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# E-Learning: Virtual Classrooms as an Added Learning Platform

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2010



This dissertation is submitted to the University of Cape Town  
in full fulfilment of the academic requirements  
for the Degree of Masters of Science in Engineering

February 2011

## **DECLARATION**

I hereby declare that this thesis titled, “E-Learning: Virtual Classrooms as an Added Learning Platform”, is my own work. All other material used in support of this thesis project have be properly referenced and acknowledged.

I know the meaning of plagiarism and declare that all the work in the document, save for that which is properly acknowledged, is my own.

University of Cape Town is the sole university to which this thesis has been submitted for a Master of Science in Electrical Engineering.

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Michael Nyarko

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Date

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A special thanks to God Almighty for what He has done for me. I could not have done this without Him. Unto Him be all glory, praise, honour and adoration now and forever more amen.

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## **ABSTRACT**

Some of the challenges being face by the South African Department of education are the shortage of teachers, over-crowded classrooms and lack of teaching resources such as textbooks. Alternative teaching and learning platforms are needed to supplement traditional classroom teaching and learning.

Virtual classrooms have been proven to offer an alternative teaching and learning platform for students and teachers to engage on an academic level. They have been widely used for tertiary course delivery, such that some universities offer their courses purely online. However, current implementations require high bandwidth in order to support the communication tools that they offer, including voice and video conferencing, a shared whiteboard, instant messaging and file sharing.

In developing countries such as South Africa the high cost of broadband internet access is a major deterrent to the country's broadband penetration rate. Users are opting for cheaper subscriptions plans at very slow dial-up speeds. This renders current implementations non-viable due to their high bandwidth requirements. As a result, virtual classroom applications that require minimal bandwidth have become necessary as a viable supplement to traditional classroom teaching and learning. Minimizing the bandwidth requirement of virtual classrooms is key to its wide adoption by general users with low bandwidth speeds.

Virtual classroom applications are collaborative applications that bring students and facilitators together on a virtual platform using computers for teaching and learning. Whiteboards are considered the main features of virtual applications and are used as the main teaching tool. Means to synchronize the facilitators' whiteboard with those of participants is necessary to facilitate real-time communication due to the limited time that virtual classroom sessions are scheduled for. The use of HTTP and co-browsing methods lead to security risks. Screen sharing technologies also add to increased bandwidth requirements of virtual classrooms due to the amount of data (pictures) transmitted between clients for synchronization.

This thesis proposed the use of text messages to facilitate whiteboard updates. Due to the small size of textual files, they can be transmitted quickly to ensure real-time communication. This method of facilitating whiteboard updates will require some level of intelligence on the client side to process the received text in order to update the whiteboard appropriately. The virtual classroom framework proposed leverages on the security provided

by IP Multimedia Subsystem network as well as its ability to support simultaneous modes of communication (video, audio, text) through SIP. IMS has been standardized as the control plane for NGN. Since NGN networks are converged and run highly managed Service Delivery Platforms, they are able to offer QoS, QoE and security guarantees, using the control functionality of the IMS.

As a real-time application, the framework must adhere to real-time communication time constraints. An evaluation platform was implemented to measure user QoE of virtual classroom services based on service latencies which included session setup delay, session joining delay and end to end communication delay between client terminals. A proof of concept IMS test-bed was developed to demonstrate the benefits of the proposed framework and provide a good platform for several evaluations to take place. The evaluation platform used and its implementation is described in order to enable duplication of it and the results obtained during this thesis. The description can also be used to extend the test-bed for further research.

Performance tests were carried out to evaluate the effect of the proposed framework to measure service latencies. Analysis of the test results show success of the virtual classroom framework, i.e. end to end delays within human visual reaction time, satisfactory session privacy and near real-time communication between session members.

Future work includes extending virtual application implementation to support video communication to offer users full interactivity and support of modern presentation styles without compromising on real-time communication of the application.

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## **GLOSSARY**

3GPP – 3<sup>rd</sup> Generation Partnership Project

A

ADSL – Asynchronous Digital Subscriber Line

AS – Application Server

B

C

CPU – Central Processing Unit

CSCF - Call Session Control Function

CSIR – Council for Scientific and Industrial Research

CRG – Communication Research Group

D

DSL – Digital Subscriber Line

E

EASSy - East African Submarine Cable System

ESP - Encapsulated Security Payload

ETSI – European Telecommunication Standards Institution

F

G

GSM - Global System for Mobile Communication

H

HD – High Definition

HSS – Home Subscriber Service

HTML – Hypertext Markup Language

HTTP – Hypertext Transfer Protocol

I

ICT – Information and Communication Technology

IMS – Internet Protocol Multimedia Subsystem

IT – Information Technology

ITU – International Telecommunication Union

IETF – Internet Engineering Task Force

IKE – Internet Key Exchange

I-CSCF – Interrogation Call Session Control Function

IARI – IMS Application Reference Identification

IFC – Initial Filter Criteria

IM – Instant Messaging

IP – Internet Protocol

IPTV – Internet Protocol Television

IVR – Interactive Voice Response

K

Kbps – Kilobytes per second

M

MAF - Multichoice Africa Foundation

MGCF – Media Gateway Control Function

MGW – Media Gateway

MIME - Multipurpose Internet Mail Extensions

MRF – Media Resource function

N

NAT – Network Address Translation

NAPTR – Naming Authority Pointer

NGN – Next Generation Network

NSC – National Senior Certificate

NEPAD – New Partnership for Africa’s Development

O

OBE – Outcome Based Education

OMA – Open Mobile Alliance

OSI – Open Systems Interconnection

P

P2P – Peer to Peer

P-CSCF – Proxy Call Session Control Function

PDF – Policy Decision Function

Prim – Presence and Instant Messaging

PLMN - Public Land Mobile Network

PSTN – Public Switched Telephone Network

PUA – Presence User Agent

Q

QoE – Quality of Experience

R

RTSP – Real-time Streaming Protocol

RTP – Real-time Transport Protocol

S

SADE – South African Department of Education

SAIDE – South African Institute for Distance Education

S-CSCF – Serving Call Session Control Function

SEG – Security Gateway

SIDN – Session Identification Number

SIP – Session Initiation Protocol

SDP – Service Delivery Platform

SDP – Session Description Protocol

SIMPLE – SIP for Instant Messaging and Presence Leveraging Extensions

SMS – Short Message Sending

SQL – Structured Query Language

T

TCP – Transmission Control Protocol

Telco – Telephone Company

THIG - Topology Inter-network Gateway

TLS – Transport Layer Security

TUP – Telephone User Part

U

UDP – User Data Protocol

UMTS – Universal Mobile Telecommunication System

UP – University of Pretoria

URI – Uniform Resource Identifier

V

VoD – Video on Demand

VoIP – Voice over IP

W

WAS – Whiteboard Application Server

WLAN – Wide Local Area Network

WWW – World Wide Web

X

XML – Extensible Markup Language

XMPP - Extensible Messaging and Presence Protocol





# Chapter 1

## Introduction

### 1 Background Information

Traditional learning is being replaced by a wide range of technology-enabled learning modalities, from podcasts and webinars to coaching on a range of electronic-learning platforms. Online learning has become very popular in the past decade, ranging from single courses being offered online to accredited universities that are purely online based [1]. Where, when and how people learn is slowly evolving. The notion of being tied down to a specific place and time for learning is becoming less appealing to modern students at higher/tertiary level.

Online based courses are mainly geared towards higher level studies. Hence students who are still in school do not get exposed to such learning modalities. Schools are being equipped with some of the latest technologies, from personal computers to whiteboard applications through projects such as Tuxlabs [2], Khanya [3] and Gauteng Online [4]. The technologies provided by these projects are exposing students to other learning modalities. As computers and internet access infiltrate classrooms, students are exposed to more learning materials, presented in a myriad of ways which meet different learning styles. This brings us to the notion of electronic learning (e-learning).

Electronic-learning (e-learning) refers to the intentional use of networked systems in teaching and learning. It can further be defined as content and instructional methods delivered on a computer (whether on CDROM, the Internet, or an intranet), and designed to build knowledge and skills related to individual or organisational goals. E-learning through the use of ICT has the potential for increasing access to and improving the relevance and quality of education [11]. E-learning is further defined by the South African Department of Education (SADE) [12] as the connection of learners to learners, teachers and professional support services as well as providing platforms for learning. Drawing on the notion of platform provisioning, virtual classrooms are additional platforms that offer promise.

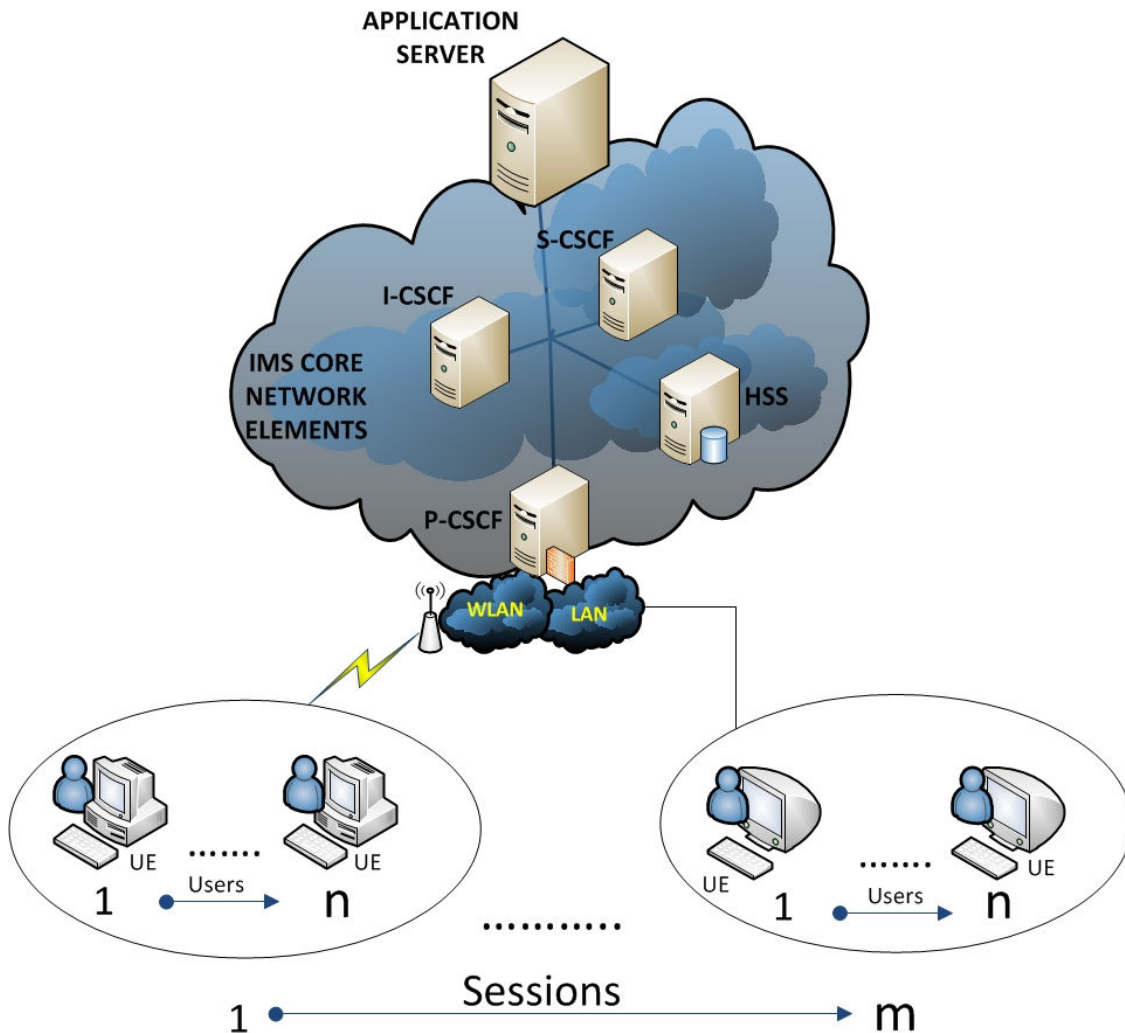
A virtual classroom involves bringing students together on a virtual platform for learning to occur. As a virtual platform, students are required to have a computer with stable Internet connection in order to be a part of a virtual classroom session. Online virtual classrooms are gaining popularity due to their inherent ability to support learning and teaching anytime, anywhere. Users can access virtual classroom services from any computer. Students without their own personal computer may use internet cafes. Security issues attached to public internet access spots such as internet cafes, requires virtual classroom applications to be secure. Furthermore, virtual classrooms are used in some companies for training purposes. Sensitive company data may be shared with participants during a virtual classroom session. This requires some level of security to be offered by the network over which the data flows between participants.

Participants of a virtual classroom need not be in a physical classroom, which removes the physical barrier of a classroom structure which limits the number of attendees to a classroom session. As a result, virtual classrooms can host a high number of participants simultaneously. In order to accommodate large classroom attendance, networks over which a virtual classroom application is deployed needs to scale well.

Virtual classrooms use technology to best mimic traditional classroom settings. By combining audio and visual communication technologies, virtual classrooms give users the illusion of being in a physical classroom. Users are required to have extra equipment such as a webcam, microphone and speakers to support video and audio communication. Virtual classrooms call for communication tools such as shared whiteboards, instant messaging and file sharing. As a result, networks (wired or wireless) over which virtual classroom applications are deployed need to support simultaneous modes of communication (ability to support video, audio and text communication) seamlessly during a given session. The IP Multimedia Subsystem (IMS) offers promise with regard to supporting simultaneous modes of communication during a given session.

The IMS was standardized by the 3<sup>rd</sup> Generation Partnership Project (3GPP) as the control plane for Next Generation Networks (NGN) [7]. It is based on the Session Initiation Protocol (SIP) and offers service integration support through SIPs ability to offer simultaneous communication modes (voice, video, IM). The IMS further separates the application service from the core network infrastructure which allows for independent scaling of the network and the application services. Virtual classroom applications require multiple and concurrent

sessions (voice, video, IM) among its participants. Figure 1.1 presents a typical virtual classroom scenario, where multiple sessions with varying number of participants can be hosted simultaneously. This requires a network that can support a high number of participants simultaneously. The IMS allows for an increase in the number of Call Session Control Functions (CSCFs). Each CSCF can be dedicated to serve a group of participants which enables a higher number of network subscribers to be served at the same time.



**Figure 1.1: Typical virtual classroom scenario**

Furthermore, the IMS is known to be a fairly secure network, offering security at two levels of the Open Systems Interconnection (OSI) Network Model; access security and network security. How the IMS achieves this is discussed in the next chapter.

Finally, the SIP MESSAGE method [49], introduced to support Instant Messaging (IM) applications using SIP, allows for short, compressed messages to be sent between SIP clients. This method can be extended to virtual classroom shared whiteboard update communication.

For these reasons the IMS was chosen as the evaluation platform for the virtual classroom framework proposed in this work.

## **1.1 Research Motivation**

The need to exploit virtual classrooms as a supplementary learning platform for students to further engage on an academic level is justified by the following reasons:

- When considering the cost effectiveness of ICT in an educational setting, definitive conclusions may not be possible. However, when considered against the alternative of building more physical infrastructure, employing more teachers, printing more textbooks, etc, the cost savings to be realised from sharing electronic resources, and the price that society has to pay for not being provided access, ICT as a means of enabling teaching and learning appears to be an attractive and necessary alternative [11].
- Noted in the annual matric results report are the different pass rates among students in different provinces and even different areas in the same province. The cost of transporting less proficient students to schools where students are more proficient is usually a hindrance to collaboration between schools. Even if it were for free, such an approach may prove inefficient and tedious. Virtual classroom are an alternative to bringing students together. Virtual classrooms cross geographic boundaries and allow students to engage on a virtual platform at a possibly much lower cost.
- Larger groups of students can be reached by a single teacher irrespective of their geographical location thereby reducing the shortage of qualified teachers in the education sector. Classes can take place from anywhere in the world, on any personal computer, as long as the user has internet access.
- Students with disabilities, for example, (deaf, dumb, limited movement, etc, can be part of a class from home without the added burden of social discrimination. This will require teachers who are adequately trained in the virtual classroom setting.

Students who cannot be in a physical classroom for any apparent reason, can still engage in classroom activity using personal computers with internet connection from where they are.

- Virtual classrooms give learners the best of both worlds, i.e. the ability to interact with others in real-time while simultaneously learning and have great fun enhancing their computer skills while improving cognitive skills such as comprehension, reasoning and problem-solving.
- Revision is often necessary for students who do not catch concepts the first time they are presented. Teachers in most cases do not get the time to revisit certain concepts during the year. Virtual classrooms sessions can be recorded, giving students the chance to review parts of the class session or re-watch the whole class session as many times as they desire, for key points that they might have missed during the class delivery.
- Furthermore, virtual classrooms offer cost saving benefits to companies who use them to train employees rather than sending the employees to various locations for training to occur.

### ***1.1.1 Problem Definition***

In South Africa, some of the challenges being faced today by the SADE are shortage of qualified teachers, over-crowded classrooms and lack of resources. Using ICT was identified as a means to help curb some of these problems [12].

Many applications that allow virtual collaborative classrooms to be held are emerging. Since these are real-time applications, each comes with a specified minimal broadband connection speed needed to support real-time communication. Minimal broadband connections of 512 Kilobits per second (Kbps) are required for some of these applications to maintain real-time communication. Intolerable end-to-end delays are experienced at speeds lower than the specified minimum requirement.

However, the high cost of broadband access still stands out as the main contributor to the low broadband penetration rate in South Africa. Customers often choose the cheaper option and, as a result, slower subscription plans such as dial-up connections. Such slow Internets

speeds make it near impossible to run real-time applications such as virtual classroom with communication features like voice and video calling, shared whiteboard interfaces, Instant Messaging (IM), file sharing and presence. This results in a large number of the general public not being able to utilize virtual classroom services. Telkom and Neotel offer basic (cheapest) dial-up Internet access at speeds of only 56Kbps and 156Kbps respectively [35]. These speeds render current implementations non-viable in South Africa.

When considering the current challenges faced by the SADE, along with existing success stories of ICT integration into education in both developed and developing countries [6], it is clear that an alternative approach to supplement current teaching techniques is required. Hence, virtual classroom applications that maintain real-time communication even with the cheaper, slower Internet access subscription plans are imperative to be better suited for developing countries such as South Africa. This will allow the general public to gain access to virtual classroom services which can be used to supplement traditional classroom teaching.

### ***1.1.2 Research Questions***

This thesis aims to overcome the above mentioned problem which, hopefully, will help curb some of the challenges faced by the SADE, discussed earlier. In particular, it will answer the following research questions.

- Are virtual classrooms a feasible option in South Africa, to encourage students to engage on an academic level?
- Can virtual classrooms be used to supplement traditional classroom teaching?
- How can virtual classrooms be adapted to suit paradigm shift in the way that learning materials are distributed, how teachers teach and the way that students learn due to evolving technologies?
- Given that virtual classrooms can be used to supplement traditional classroom teaching, what effect will an added learning platform have on students' learning experience, in and outside the classroom?

## 1.2 Thesis Objectives

This thesis investigates the plausibility of virtual classrooms as an added learning platform for students to further engage on an academic level in groups with or without the facilitation of a teacher. Further, this thesis aims to investigate and analyse a suitable IMS-based virtual classroom framework, capable of supporting virtual classroom services, accessible by users with low-speed internet connections (limited bandwidth). The proposed framework should be analysed through an evaluation platform. The thesis objectives can be summarised as follows:

- The primary object of this thesis is to investigate the feasibility of using text-based instant messaging to facilitate shared whiteboard updates during a virtual classroom session, with an aim to minimize bandwidth requirements of virtual classroom applications.
- To design, implement and evaluate a virtual classroom application with support for voice conferencing, shared whiteboard, IM, presence and file sharing, that maintains real-time communication.
- To provide an overview of the current state of South Africa's communication infrastructure and its ability to support virtual classroom applications.
- To investigate the number of students in South Africa who have access to computers with internet access, in order to access virtual classroom services.

In order to evaluate the success or failure of the proposed framework, two metrics are defined to measure the degree of success. These include service latency and service features. Service latency is evaluated based on real time communication among participants engaged in a virtual classroom session. Service features are evaluated based on user expectation of the virtual classroom service. Virtual classroom sessions are time bound (a facilitator has a limited amount of time to deliver course content to students), and as such communication delays among participants need to be kept at a minimum in order for the facilitator to effectively deliver all the course content in a given session. Furthermore virtual classroom applications are categorized as real-time applications and as a result need to adhere to certain time constraints such that incurred delays do not negatively affect users' QoE. Human visual reaction time is used as the benchmark for comparison of the evaluation results.



### **1.3 Scope and Limitations**

Several limitations have been set to reduce the scope of this study. Virtual classrooms are made up of many components that give the user the full illusion of being in a physical classroom. These include, but not limited to, video, audio, shared whiteboard, instant messaging and file sharing. Video communication is out of the scope of this work due to its high bandwidth requirements.

This work only considers the application and services plane and as a result, mechanisms (e.g. buffering techniques) to reduce user incurred end-to-end delay in access technology and network entities are out of the scope of this work.

Although the IMS forms part of the proposed framework, only the security features in the IMS network and its ability to support applications such as virtual classrooms are highlighted in this work. The work further assumes a single IMS network and one domain. Communication with clients on different domains is out of the scope of this work.

The IMS uses many protocols standardised by the IETF: four of which are used extensively in this thesis. These include SIP, SDP, MSRP and RTP. A full discussion regarding the inner-workings of these protocols is beyond the scope of this thesis and readers are advised to consult the relevant Request for Comments (RFC) documents.

### **1.4 Thesis outline**

The rest of the thesis is outlined as follows:

#### **Chapter 2**

This chapter discusses work done by others in and around the area of this research. These papers are reviewed based on their significance pertaining to the project. It further discusses current implementation architectures and highlights the limitations of such architectures. Useful work and concepts are extracted and applied to this work.

#### **Chapter 3**

This chapter discusses the architectural requirements of virtual classrooms in the IMS. The various entities needed to support such applications are discussed together with the roles they play. A list of design considerations are provided together with the proposed framework for IMS-based virtual classrooms.

#### Chapter 4

This chapter defines the evaluation platform used in this research. The requirements and limitations of the test-bed are introduced, along with the test-bed architecture. The various test-bed components are discussed together with their functionality. Details of the test-bed software and hardware are included in Appendix B and C.

#### Chapter 5

This chapter analyses the evaluation platform. Performance tests carried out analysed service latency with regard to session setup delay, session joining delays and session communication delays. Service features are analysed based on users' expectancies of the virtual classroom application. The results obtained using the test-bed are presented and analysed.

#### Chapter 6

This chapter presents a set of conclusions that were drawn from the evaluations performed in chapter 5. Future works in this area of research are further recommended.

# Chapter 2

## Related Work

### 2.1 Background information

The emergence of the World Wide Web (WWW) has paved the way for a new life of academic learning. Traditional methods of academic learning which involve people being in a single venue at a specific time for learning to occur is fast becoming unsuited to the life style of many people today.

The Internet opens doors for new academic learning paradigms. Online classes have become more popular over the last decade. E-learning grew by 86% between 2006 and 2008 with regard to the total number of courses delivered. Virtual Classrooms in the same light grew by 330% within that same period [13]. These percentages are a clear indication that more students are taking-up online courses as opposed to traditional classroom classes. The popularity of online classes has grown so much that some university programs are purely online based, offering all their courses over the internet [1].

In another research based on the pilot evaluation of Learning Activity Management System (LAMS) [9], 80% of students preferred to discuss their ideas in a virtual environment, while only 15% preferred a physical classroom. This further highlights the paradigm shift in student – student interaction and learning in general.

### 2.2 E-learning Models

The intentional use of ICT in education support is what is referred to as e-learning; it encompasses learning at all levels, both formal and informal, from simple tutoring to the delivery of whole courses. ICT refers to a diverse set of tools and resources used to communicate, create, store and manage information. These tools and resources include computers and the internet, telephones, television and radio. Online learning was made possible by integrating Information and Communication Technology (ICT) into education. ICT enables students to take courses online. As an internet based academic learning

platform, students taking online courses require computers with internet access in order to access course content, assignments and tests. E-learning course deliveries are usually achieved through two design approaches; asynchronous (non-real-time) and synchronous (real-time) each with its own pros and cons [59]. The two approaches are presented below together with their advantages and disadvantages.

### ***2.2.1 Asynchronous (Non-real-time) Model***

Online e-learning is referred to as asynchronous learning. Students work independently through a set of course objectives and correspondence among themselves as well as with the instructor happens via email and discussion boards. The students are often given a time frame in which to perform given tasks.

Thomas [14] advocates this model. The author argues that asynchronous conversations allow students to participate in virtual classroom discussions without being forced to an immediate response. The flexibility offered to students with regard to their engagement with the classroom session appeals to a certain group of students.

However, the short fall of asynchronous learning is its inability to support real-time communication. Electronic mail, which is the main form of student and instructor communication, is prone to delays. One is never certain as to when the recipient will read the email or when it will be delivered to the recipients' inbox. Discussion forums also require the facilitator to check the online discussion board periodically for questions posted by students. This is inefficient and time wasting, especially if the instructor checks the board and finds nothing posted.

### ***2.2.2 Synchronous (Real-time) Model***

The synchronous approach often involves the use of a virtual classroom to aid course delivery. With this model, students engage with the instructor on a real-time basis. Student and instructor communication occurs through audio, video, instant messaging and usually a shared whiteboard interface. Virtual classrooms grew more popular among students, due to their real-time nature, as it gave them the opportunity to address issues concerning course materials during the lesson delivery.

Premchaiswadi et.al [15] proposed the use of Real-time Messaging Protocol (RTMP) to inspire creativity in e-learning. The authors argued that interaction between students and instructors on a real-time basis is imperative to address issues that students may have immediately. RTMP is a proprietary protocol developed by Adobe Systems (formally known as Macromedia). It is used with Macromedia Flash Media Server for video and audio streaming over the internet. However, the disadvantage of the system is that Macromedia Flash can cause security issues. Macromedia Flash files are not password protected or encrypted and can transfer viruses when downloaded on a computer. Executions of Adobe Flash players in 2009 were the second-most attacked vulnerability as reported by Symantic in an Internet Security Threat report [10].

Das et.al [13] also mentioned the need for student and instructor interactivity during a virtual classroom session to address ad-hoc queries that students may have. The authors further analysed virtual classrooms vs traditional classrooms on the basis of cost implications, both monetary and time. The authors showed that virtual classrooms are cost effective solutions, in terms of time and money, and can reduce the cost of education delivery. Businesses which regularly train new employees stand to benefit from the use of virtual classrooms to aid training of their new employees in terms of cost and time.

## **2.3 Virtual Classroom Architectures**

The functional needs of a virtual classroom may differ depending on what it is used for. Virtual classrooms may be used to teach or used to discuss business related matters from various parties involved (business meetings, brainstorming sessions). Two main virtual classroom architectures exist to cater for these two scenarios. These are discussed below.

### ***2.3.1 Role-based Architecture***

The role based architecture is implemented in [60], [32] and [37]. In this case the virtual classroom is used for teaching a group of individuals. In this architecture each participant is assigned a specific role. The different roles include:

- Teacher (Instructor) act as a facilitator of a classroom session. They also develop courseware to be taught during sessions.

- Class expert helps students solve technical problems (i.e. no sound, microphone problems, etc) that they may encounter during a session.
- An administrator is responsible for maintaining all aspects of the distance learning and all aspects of the learning system such as user access rights and student registrations [60].
- The team leader is a person in charge of a group when students are divided into groups. The team leader may also be in charge of the whole class when the facilitator is absent.
- Students are the people who access the course content. That is, the people who are taught by teachers/ instructors.

Each of the roles has a set of responsibilities and privileges. For example, in [32] and [37] the teacher has control over the microphone and the whiteboard facilities. Having access to the microphone gives the teachers the privilege to speak while the rest of the class listens. The teacher also has the ability to grant participants access to these facilities. A role policy is used to assign roles to participants. The implementation of the role policy differs and is subject to the designer's preference.

Work done by Liu et.al [16] allowed students to switch between roles, giving them different privileges. This is particularly useful during break away sessions, where different students can take up the team leader role.

### ***2.3.2 Collaborative Architecture***

Another approach to virtual classroom architectures is based on the notion of collaboration. Collaboration is at the forefront of a variety of classroom techniques that are currently being advocated [61]. Collaboration is based on the notion that students master certain subjects better when they work in groups with equal “rights” rather than as individuals [62]. Furthermore, group work is beneficial to problem solving [72].

Collaborative learning is a well-established group work method that provides a useful alternative to teacher-fronted classes [72]. Collaborative learning has other benefits in the context of teaching and learning, including developing the students' social interaction skills, communication skills and much more due to its “all participants are equal” policy [74].

Traditional classrooms foster group work for certain activities and as a result virtual classroom applications need to adhere to this requirement. Commonly found in virtual classroom course delivery sessions is what is known as “break-away” teams. During a session, a facilitator may group certain participants together to form smaller groups. These groups are given a subject to discuss or a problem to solve and after the allocated time has elapsed, the assigned team leader reports back to the larger class. These “break-away” teams resemble traditional classroom setting where a teacher divides the students into groups to work through a certain problem.

This architecture does not define any roles and all participants are considered equal. This kind of virtual classroom architecture will be better suited for business meetings or business brainstorming sessions where all parties are given the same privileges.

## **2.4 Building Blocks of Virtual Classrooms**

Recent trend in technology points towards the integration of services into single devices. Just over two decades ago one had a television set, a video recorder and a hi-fi system for entertainment (video and audio) but today, a single computer will suffice. Printers now do more than just print papers, but perform other functions like scanning, photocopying and emailing. It is clear that people want single devices that do more for them than having multiple devices performing different but related functionalities. Cellular phones are the winners in this regard.

The aim of a virtual classroom is to mimic traditional classrooms. To achieve this, virtual classrooms are equipped with various communication tools to support voice, video, instant messaging, file sharing and presence, all integrated into one application. These communication tools provide support for both collaborative and individualized communication. The following subsections discuss the different building blocks of virtual classrooms.

### **2.4.1 Whiteboard**

A whiteboard is mostly seen as the main feature of a virtual classroom and sometimes referred to as the “chalkboard with an electronic edge”. The idea behind it is to mimic traditional blackboard functionality as best as possible. The physical board is represented by

a white rectangular drawing space. The chalk is replaced by either the mouse or an external electronic writing pen. These whiteboards are equipped with tools that allow users to draw shapes (triangles, rectangles, circles, etc), text and free hand drawing. Whiteboards are further equipped with colour selection menus and a variety of text editing tools. Some virtual classroom implementations have support for power-point presentations to accommodate modern presentation styles. Slides are viewed by all participants yet controlled by the facilitator of the session. A means to broadcast the content of the shared whiteboard to all participants poses a challenge for virtual classroom designers.

WiZiQ [32] recently implemented a screen sharing feature. This feature uses a 'screen-sharing codec' that transmits the presenter's screen as a series of images at a specific frame rate to the server, which in turn transmits these images to all attendees' screens [34]. The screen sharing feature has been optimised for users with 500Kbps data transfer rate. In South Africa, Telkom [54] and Neotel [48] offer basic (cheapest) internet access at speeds of only 56kbps and 156kbps respectively [35]. Another relatively cheaper option is the Asymmetric Digital Subscriber Line (ADSL) 384kbps option currently being offered by several Internet Service Providers [36]. Notably, these are too slow to support what WiZiQ offers.

Zhang et.al [17] employed a co-browsing technique using HTTP and Java Servlets. The URL of the facilitator's current webpage is dynamically broadcast to all participants via a Proxy Server. The participants' browsers load the facilitators URL to ensure screen sharing. Like the many other web-based virtual classroom solutions, [15, 16, 17, 60], security remains a problem. HTTP proxies are not always secure as they lack security features and are often left open [8].

#### ***2.4.2 Audio and Video Communication***

Although out of the scope of this work, video communication is discussed briefly for completeness. Video communication is known to be one of the major bandwidth consumers in virtual classroom applications. Bad implementations result in heavy delays which lead to a low user Quality of Experience (QoE). Advances in High Definition (HD) video over the internet brought advances in both visual quality and narrowing of Round trip latency for realistic dialog. Video quality and clarity allows students to better engage with the instructor and maintain student attention during a session [63].



Audio quality is vital to student's clear understanding of the offered content– might be the worst distraction of a session and needs to be the one aspect that is well maintained (difference in quality is user equipment dependent). A truly interactive communication requires timely and high-resolution video and audio transmission over a network, with end to end latency below 100 ms. Even when captured and transmitted independently, the video and audio must be kept synchronized and thus both transmitted with the lowest latency [64]. A broadband connection is required in most cases to achieve this.

Yang et.al [18] proposed the use of text to speech technology to reduce the bandwidth requirements of virtual classroom applications. Textual files are generally smaller and can be transmitted quickly when compared to video and audio files. The added advantage of their system is that the user did not have to read all the time but could listen to what was being said while concentrating on the whiteboard presentation. The disadvantage, however, of the system was that the synthesizing quality of the engine was not very good, resulting in bad audio quality. Bad audio quality is known to lead to low user QoE of the virtual classroom application.

### ***2.4.3 Instant Messaging***

Instant Messaging (IM) is a form of real-time communication between two or more people based on typed text messages. It requires the least bandwidth when compared to other virtual classroom communication tools such as video and audio calls, and can be the fastest means of communication during a session when there is limited bandwidth. IM has proved to be a very useful communication tool in a virtual classroom setup.

A major advantage of IM is that it complements visual communication for the audibly impaired members of a session and helps those who cannot support video and audio to actively engage in a session. IM is synonymous to students passing small notes around to one another during a group session. These messages can either be public whereby all members of the session are permitted to read or private where only a limited set of persons are allowed to read it.

The instant messaging application, MXit [26], launched in 2003, introduced an innovative twist in tutoring in 2007. Math on MXit, or Dr Math [27, 28] as it's popularly known, is an initiative launched by the Meraka Institute of the Council for Scientific and Industrial

Research (MI CSIR) that has demonstrated the effectiveness of a chat support service in reaching out to young people.

Being a mobile application, Dr Math is restricted by the physical limitations of mobile phones such as screen size, keypad and dual camera for video interaction. The small screen sizes make it difficult to see text hence forcing the tutors to type many lines of text to explain concepts that a simple diagram could have simply explained. Communication with participants is limited to IM, which do not give students full interaction. Virtual classroom sessions have time limits per session. Reading of text as the only form of communication will result in long sessions or less material being covered per given session.

However, MXit exemplifies the need for virtual classrooms to support chat. Its popularity suggests that students enjoy chatting and some may prefer chat as a means of communication on a virtual platform. Having a chat feature on virtual classrooms will further aid students who express themselves better using typed text.

Martin [33] admonished facilitators to encourage the use of text chat for discussions if the virtual classroom class session has more than 20 students.

#### ***2.4.4 Feedback Mechanisms and Interactions***

A virtual classroom requires a means for the facilitator to ask questions and get feedback from the students attending the class when used for teaching. With certain implementation, the facilitator is the only one who controls the microphone, hence giving access to individual students one after the other may prove time consuming and very ineffective. As a result, virtual classrooms are equipped with polling mechanisms, that allow a facilitator to ask general questions and all participants can answer simultaneously by selecting an answer of their choice. The results are visible to the teacher.

#### ***2.4.5 Resource Sharing***

Resource sharing refers to the distribution of course content prior to, during and after a virtual classroom session. Students are given access to course related material such as presentations slides, worksheets, assignments and past virtual classroom sessions.

Thutong [31] is South Africa's educational portal launched by the government of South Africa. Thutong has proven to be a very useful resource, allowing students and teachers to get access to various academic materials. However it is limited to the provisioning of educational material and subject discussions through an online forum. The forum, which is the main form of communication between students and instructors, categorizes Thutong under the asynchronous e-learning model discussed earlier.

Thutong exemplifies the need to incorporate file sharing in virtual classrooms. By making electronic versions of course materials available to students, less textbooks will be required which helps curb the issue of textbook unavailability prevalent in developing countries.

## **2.5 IMS Features that Enable Support for Virtual Classrooms**

As discussed in the previous session, virtual classroom applications combine several services into one application. These services include voice calling, video calling and instant messaging. Each of these services come with their own set of Quality of Service (QoS) requirements. Some commercial implementations of virtual classroom applications are offered over the open Internet. The Internet is a best effort network, meaning communication is unreliable and can often be intermittent. This is not ideal for conference calls (business or teaching) and can be extremely annoying to the end user. Furthermore, security cannot be guaranteed over an unmanaged platform. It is possible to offer reliable and secure IP based services by using managed service delivery platforms. Virtual classroom applications need to run over highly managed Service Delivery Platforms (SDPs) which provide QoS guarantees.

The IP Multimedia Subsystem (IMS) is an architectural framework which provides the necessary control functionality required to run managed SDPs over Next Generation Networks (NGNs). This network shifts the focus of network providers from access provisioning to service provision. IMS allows for the horizontal integration of applications which are being developed and deployed at an alarmingly rapid rate. However, its wide acceptance relies heavily on how best network providers differentiate their services from existing services over other non-IMS networks. This service differentiation can be done by increasing security, greater service integration and improved reliability through QoS provisioning [38]. Virtual classroom applications are a means to integrate existing services such as voice, video and text communication. The IMS offers service integration support,

required by virtual classroom applications, through SIP's ability to offer simultaneous communication modes (voice, video, IM).

The simplicity of the IMS with regard to session setup and termination together with its architecture which separates the core entities from the application layer allows for easy incorporation of new applications into the network. This will allow ISP's to easily integrate a virtual classroom application into their network. Users have full access to all applications, including Voice over IP (VoIP), Video on Demand (VoD), Presence, Internet Protocol Television (IPTV) and many more that are deployed in the application layer. These existing services can be harnessed to provide a more comprehensive virtual classroom experience. For example, recorded virtual classroom sessions could be offered as VoD, leading to another source of income for ISPs.

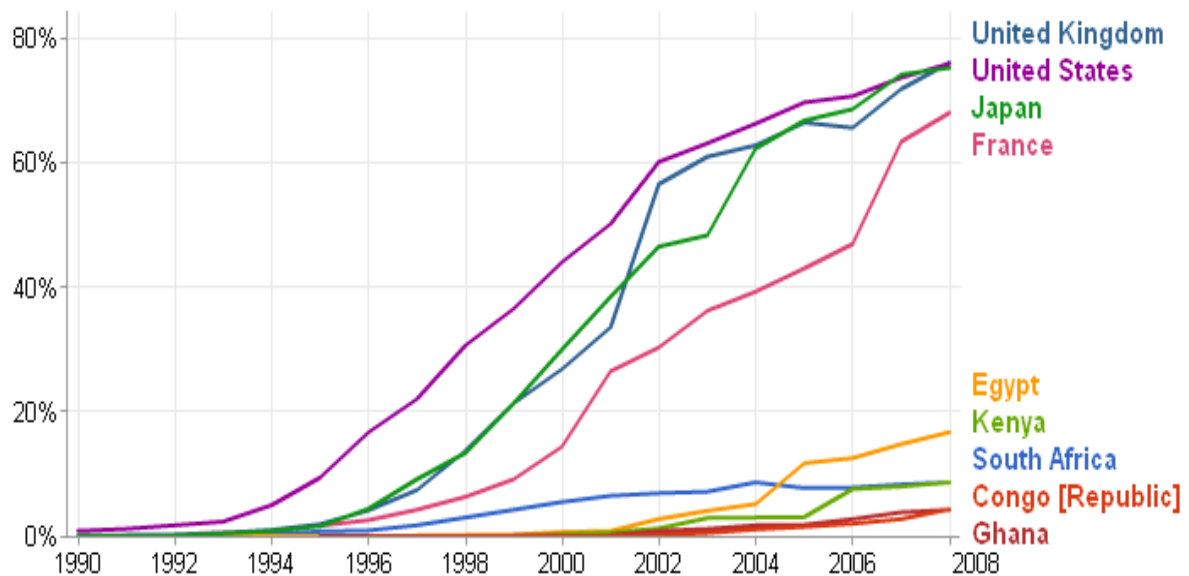
Furthermore, the IMS is access network independent hence can be used over a Global System for Mobile Communication (GSM), UMTS, WLAN and Broadband connections. Users do not need to have multiple accounts to access the various applications. Therefore, IMS flexibility enables virtual classrooms to be offered over any access network technology, fixed, mobile, wired or wireless.

Since NGN networks are converged and run highly managed SDPs, they are able to offer QoS, QoE and security guarantees, using the control functionality of the IMS, needed by virtual classroom applications. Further details into IMS security, which is key in virtual classroom applications, can be found under Appendix A.

## **2.6 Internet usage**

As a subset of the thesis objects, an investigation into the current state of ICT infrastructure in South Africa is presented briefly below. South Africa and Africa at large have lagged behind in the development and deployment of internet access, resulting in limited access to high bandwidth and large scale internet infrastructure. But this is rapidly changing with recent reports of a surge in the number of internet users. Reports revealed that the number of South African internet browsers increased by an incredible 163% between 2006 and 2007 [29, 30]. Currently 10.8% of the population have internet access [29, 30] which amounts to approximately 5.258 million people. The majority of these people are in the business sector and higher education institutions. This number of the population with internet access is very

low when compared to developed countries as depicted in **Error! Reference source not found.**



**Figure 2.1: Internet usage 2008 [50]**

**Error! Reference source not found.** depicts the percentage of country's populations that have access to internet or use the internet. This percentage is plotted over several years. Notably, each countries plot shows an increase in the number of people that have access to the internet. Much of the increase can be attributed to several Telecommunication Companies (telcos) and increased bandwidth availability (Africa to Europe and Asia). Further discussion on the factors causing the increased bandwidth can be found under Appendix A.

In South Africa, new innovative initiatives by leading telecommunications company, Telkom-SA, such as the introduction of Asymmetric Digital Subscriber Line (ADSL) and other broadband technologies have played a role. Cellular operators such as Vodacom and MTN made significant contributions with the introduction of 3G and High-Speed Downlink Packet Access together with wireless broadband offered by Sentech and iBurst. All these initiatives offer users more access to the internet. Prices are set to decrease or at the very least be competitive with the surfacing of a second fixed-line network operator, Neotel. Consumers are optimistic that the competition will result in better services being offered. A comparison of prices for the two companies, Telkom and Neotel, can be found in [35].

To address the issue of internal bandwidth availability, SA being the host nation of the biggest sporting event in the world, the FIFA World Cup 2010, saw much being done to better the infrastructure that forms the back-bone of ICT in preparation for the event. Telkom, SA's largest telecommunication company laid down approximately 128 000 cable kilometres of optical fibre [54]. This has significantly improved internet speeds and bandwidth in the country. Furthermore, Neotel chose to put up their own infrastructure as the second PSTN operator during its establishment. This increased bandwidth available to the general public due to reduced traffic congestion that a single PSTN network was prone to as some businesses and home owners opted for Neotel's services. The spread of customers also lead to better service delivery and improved Quality of Experience (QoE) for the general user.

However, even with the improvements in infrastructure and the increased internet speeds, prices still remain high for the general public to afford. Industrialists are offering more internet access subscription plans and increased usage limits due to the available bandwidth but not lower prices [55, 36]. South African consumers still cannot afford the prices that ISPs are currently offering [56]. On average, accessing the Internet cost Africans 50-100 times more than what it cost consumers in Europe, Asia and North America [57]. This high cost results in the general user opting for the cheaper price options at speeds that cannot adequately support current implementations of virtual classrooms.

There is a need to provide less bandwidth demanding virtual classroom applications suitable to the general user with their slow internet subscription plan. By this, more customers (individuals, schools) will have access to virtual classroom services which can be used to supplement traditional classroom teaching.

## **2.7 Chapter Discussion**

Virtual classroom applications have the goal of replicating traditional classroom settings, from teacher to student communication to communications between students. Reviewed literature showed vendor specific implementations. For example, a typical classroom requires students to pay attention to the teacher as a lesson is delivered. Paying attention to the teacher however, places no limits on students interacting with one another to clarify something the teacher said but they did not understand. Current implementations,

specifically WiZiQ [32] and Elluminate [37], gives the teacher full control of the microphone (audio communication). Only one person can be speaking at any given time. A student would have to disrupt the whole class by requesting permission to get the microphone prior to asking a question which a fellow student perhaps could have explained privately. This is not in-line with mimicking traditional classroom settings where a student is free to ask a quick side question without disrupting the whole class session. Students also have the choice to choose who they are listening to at any given time. This freedom is not incorporated in current virtual classroom applications.

Furthermore the chat feature offered by applications of this nature is usually multi-chat. This means that everyone can read what the other says. Some implementations that support private chat also give the teacher the ability to disable it. This again is not in-line with traditional classroom settings where private conversations, although not ideal, are not inhibited from occurring.

Virtual classrooms that take into consideration the freedom of students in a physical classroom are imperative to be best accepted among young users.

Several common practices and tools with regard to virtual classrooms were identified and are used in the design of the proposed framework discussed in the chapter to follow.

# Chapter 3

## Proposed IMS-Based Virtual Classroom Architecture

### 3 Introduction

Chapter 1 discussed the benefits of virtual classrooms and their ability to supplement classroom teaching. Chapter 2 reviewed literature related to virtual classrooms and identified several existing implementations. The implementations themselves varied in their approach and complexity to resolving some of the challenges faced by virtual classrooms. This chapter begins by looking at the requirements of virtual classrooms based on reviewed literature before presenting the proposed framework.

#### 3.1 Design Considerations

When designing virtual classroom applications it is important to keep in mind the target audience and potential users in order to meet their specific needs. To ensure the virtual classroom framework is suitable for all players involved, a number of key success elements were identified. These ensure that the proposed framework includes all the necessary functionalities and satisfies the requirements of the users and telcos. These requirements are discussed briefly below.

##### The User

Two categories of users are identified in a virtual classroom environment when used for teaching: the facilitator and the students. In order for a facilitator to effectively deliver a virtual classroom lesson to a group of students, they will require the following:



- A means to communicate with the students verbally (voice communication), textually (instant messaging) and graphically (shared whiteboard interface). Textual communication is mainly required for students who are audibly impaired and some students who may not have the necessary equipment (speakers) to support audio communication. IM is also the communication tool to fall back on in the event that voice communication gets disrupted due to technical failures.
- A means to be informed of the students presence status in order to take the necessary action if a particular student experiences technical difficulty and gets disconnected from the virtual classroom session.
- A means to get feedback from the students in order to establish the level of understanding of the students concerning the material delivered during the virtual classroom session.
- A means to provide course content to students (either course content that are presented during the virtual classroom session for review purposes or extra material concerning the topic discussed during the virtual classroom session).
- Session privacy (allowing only permitted students to join a virtual classroom session).

The students will also require similar features in order to engage with the facilitator during the virtual classroom session. These requirements include:

- A means to communicate with the facilitator verbally, textually and graphically to ask questions, comment or request an explanation.
- Support for private conversations (voice and/or text) to allow students to get clarity on a subject matter from a colleague without disrupting the whole class.
- A means to get course material (facilitator notes, past session data).

### **The Telcos**

The requirements for telcos differs from those of the users. These non-functional requirements include:

- The use of standardized NGN/IMS components, interfaces and protocols to ensure an easy integration process of the proposed framework into their existing network as

well as to minimize capital expenditure needed in deploying virtual classroom services.

- Access network independence to the virtual classroom application service in order to provide service to a larger pool of clients using different access technologies.

Drawing from success elements in related work, other functional requirements on a virtual classroom application include:

- Virtual classroom sessions are time bound (a facilitator has a given amount of time to deliver course content). As a result virtual classrooms need to be as real-time and reliable (guaranteed QoS) as possible for an efficient use of the allocated time.
- Due to the number of sessions that can be held simultaneously with varying number of participants each, virtual classrooms need to be scalable and have the ability to support a large number of participants simultaneously.
- Lastly, the 3GPP and ETSI TISPAN defined standard IMS functional components and interfaces. This is necessary to ensure interoperability between IMS components originating from various vendors. The proposed virtual classroom framework should reuse, where possible, these standardised components and interfaces thus limiting the need for new functional entities in the IMS architecture.

### **3.2 Architectural Requirements**

As mentioned before, it is crucial that the proposed framework utilizes standard IMS and NGN functional components, interfaces and protocols defined by 3GPP and ETSI TISPAN, to prevent interoperability issues that may arise due to vendor specific architectures and other IMS and NGN entities. The required elements are discussed below. Section 3.3 details the full proposed architecture which makes use of these elements. Figure 3.1 presents a schematic of the proposed architecture and illustrates how the following architectural requirements are met by using standard entities, interfaces and protocols.

#### **3.2.1 IMS Control Functions**

IMS core elements are required to process SIP signalling within the IMS for the establishment of sessions. Three types of CSCFs are required to perform these functions.

These include the P-CSCF, I-CSCF and S-CSCF which make up the control plane (IMS layer) in the NGN architecture.

**P-CSCF:** The Proxy-Call Session Control Function serves as the first point of contact to the IMS network and requires a SIP based Gm interface to communicate with the User Equipment (UE). SIP REGISTER methods are initially terminated at this IMS entity which ensures that registration or session requests are passed to the correct home network S-CSCF. The P-CSCF's main role however, is to route incoming packets to the correct S-CSCF and thus it has the inherent ability to support path and service-route headers. Two header types are supported, the initial one being created during the registration process and used to validate routing information and the second being created from the record-route headers in the initial invite and associated session dialogue [66]. The IMS core may contain more than one P-CSCF for the sake of scalability. The ability of the IMS to support multiple P-CSCF is key in ensuring the scalability of virtual classroom applications.

**I-CSCF:** The Interrogating- Call Session Control Function is a core entity which decides which S-CSCF a user should be assigned to. The I-CSCF retrieves user location information from the Home Subscriber Server (HSS) using the Diameter protocol over a Cx interface. In some instances it acts as a Topology Inter-network Gateway (THIG) by encrypting parts of the SIP message containing confidential network information.

**S-CSCF:** The Serving- Call Session Control Function acts as a SIP registrar for all users on the IMS network by maintaining a binding between the user's location and the SIP address. Included among its functions are routing and translation, provision of billing information to mediation systems, maintaining session timers and interrogation of the HSS to retrieve authorisation before providing a certain service to the user. The S-CSCF requires a SIP based ISC interface to communicate with Application Servers (AS) and a Diameter based Cx interface to communicate with the HSS.

### **3.2.2 Application Server**

Application servers provide NGN/IMS services to the user. These applications are SIP entities responsible for hosting and executing services.

For the purpose of a virtual classroom service, a Whiteboard Application Server (WAS) is required. It receives requests from the clients UE via the S-CSCF. The WAS requires a SIP based ISC interface to the S-CSCF to receive SIP request messages. It maintains dialog state and participates in all requests sent on the dialogs it helped establish. However, its participation is limited to logging received messages from UEs during a virtual classroom session.

The WAS facilitates the establishment of virtual classroom sessions by providing UEs a means to locate virtual classroom session initiators. It maintains a database of current virtual classroom initiators and provides this information (SIP URIs of the initiators) to client UEs upon request. The WAS also provides role-based registration (allowing a client to register as a particular subject specialist (algebra, photosynthesis, fluid mechanics, etc)).

The WAS further integrates the functionalities of a Presence Server (PS) to inform session facilitators of the presence status of their session participants. Real-time updates of participants presence is required to alert the facilitator if a participant experiences technical problems. Including the functionality of a PS with the WAS removes the need for another functional entity in the proposed virtual classroom framework. Having another functional entity will inevitably increase the complexity of the framework as well as increase the required signalling during a virtual classroom session setup, session communication (during the session) and session termination. This may lead to unnecessary signalling overhead. The initial SIP INVITE message from a UE contains enough information (user name, sip address, location) to build the user's presence information. Other user presence information (mood, status, etc) can be attached to the SIP INVITE SDP body if needed. The WAS extracts this presence information from the received initial SIP INVITE.

The WAS is also required to provide a session record database, where students can retrieve past virtual classroom session data. A File Transfer Protocol (FTP) interface is required between the UE and the WAS to allow users to request past virtual classroom session data for review purposes.

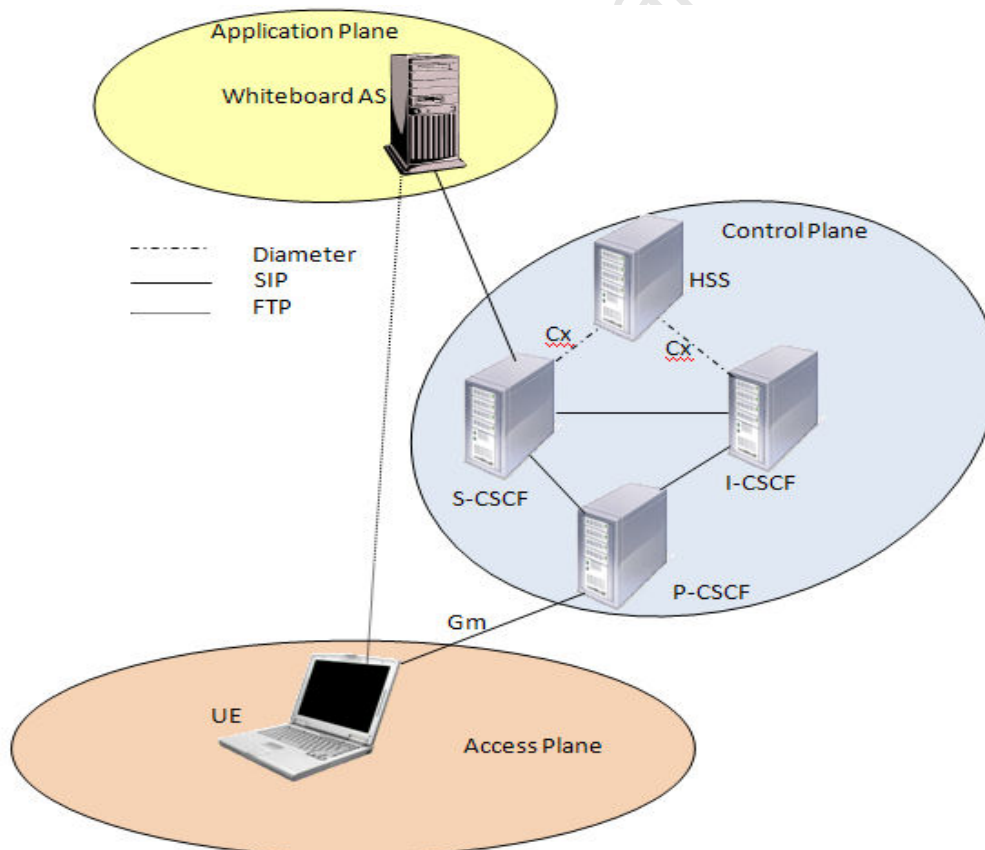
### 3.2.3 User Equipment

An IMS terminal is required by a user to access IMS services. Two interfaces are required on the IMS terminal: A SIP based Gm interface to the P-CSCF to request a virtual classroom service and a FTP based interface to download and upload content from and to the application server.

The IMS terminal is required to support virtual classroom communication tools (instant messaging, voice calling, and shared whiteboard). The IMS client running on the terminal is required to allow IMS registration, virtual classroom session initiation, virtual classroom session joining, communication preference changes, file transfers and searching for online users by role (algebra, photosynthesis, fluid mechanics, etc).

### 3.3 Proposed Framework for IMS-based Virtual Classroom Architecture

Figure 3.1 illustrates the architecture of the proposed virtual classroom framework. The architecture makes use of standard IMS and NGN functional components, interfaces and protocols.



**Figure 3.1 Proposed virtual classroom architecture**

The framework introduces a Whiteboard Application Server (WAS) in the application plane, to provide virtual classroom services (discussed earlier) to clients. As mentioned earlier the IMS offers support for multiple CSCF dedicated to different set of users, for scalability purposes. Although not shown in the diagram, different CSCF can be assigned to different virtual classroom sessions.

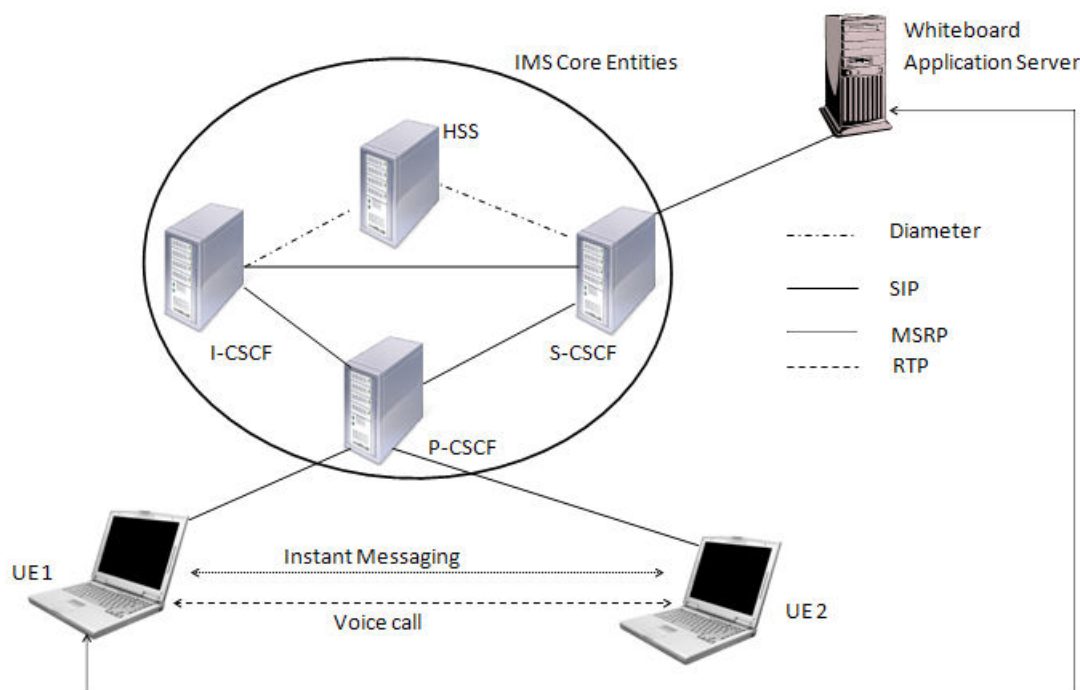
NGN/IMS networks support session based communication. Sessions such as voice calling and instant messaging, used in providing virtual classroom services, are established based on the offer/answer model. One of the users (the offerer) generates a session description (the offer) and sends it to the remote user (the answerer) who then generates a new session description (the answer) and sends it to the offerer. For example, in order to establish a session (e.g. voice call) between two users, the first user sends an offer in the form of a SIP INVITE to the second user. The first user attaches a session description in the form of a SDP to the SIP INVITE. Figure 3.2 presents an example of SDP session description that the first user (Alice) sends to the second user. It contains among other things, the subject of the conversation (s = Lets Talk), IP address (c = IN IP4 251.12.11.1), the port number where Alice wants to receive audio (m = audio 20000 RTP/AVP 0) and the audio codecs that Alice supports (0 corresponds to the audio codec G.711 /tt-law). Note that this session is suppose to take place immediately the session description is received. That is why the t = line is t =0 0. The 'v' and 'o' SDP types provide the version and user identity respectively.

```
v= 0
o= Alice 320000 321000 IN IP4 251.12.11.1
s= Lets talk
c= IN IP4 251.12.11.1
t= 0 0
m= audio 20000 RTP/AVP 0
a= sendrecv
```

**Figure 3.2: Example of an SDP session description**

In order for the session to be established, Alice also needs to know the second users transport address as well. SIP provides a two-way session description exchange, referred to earlier as the offer/answer model described in [47]. The receiver responds to the received SIP INVITE and attaches a similar session description SDP. After the offer/answer exchange, both users have a common view of the session to be established (formats to use, transport address for

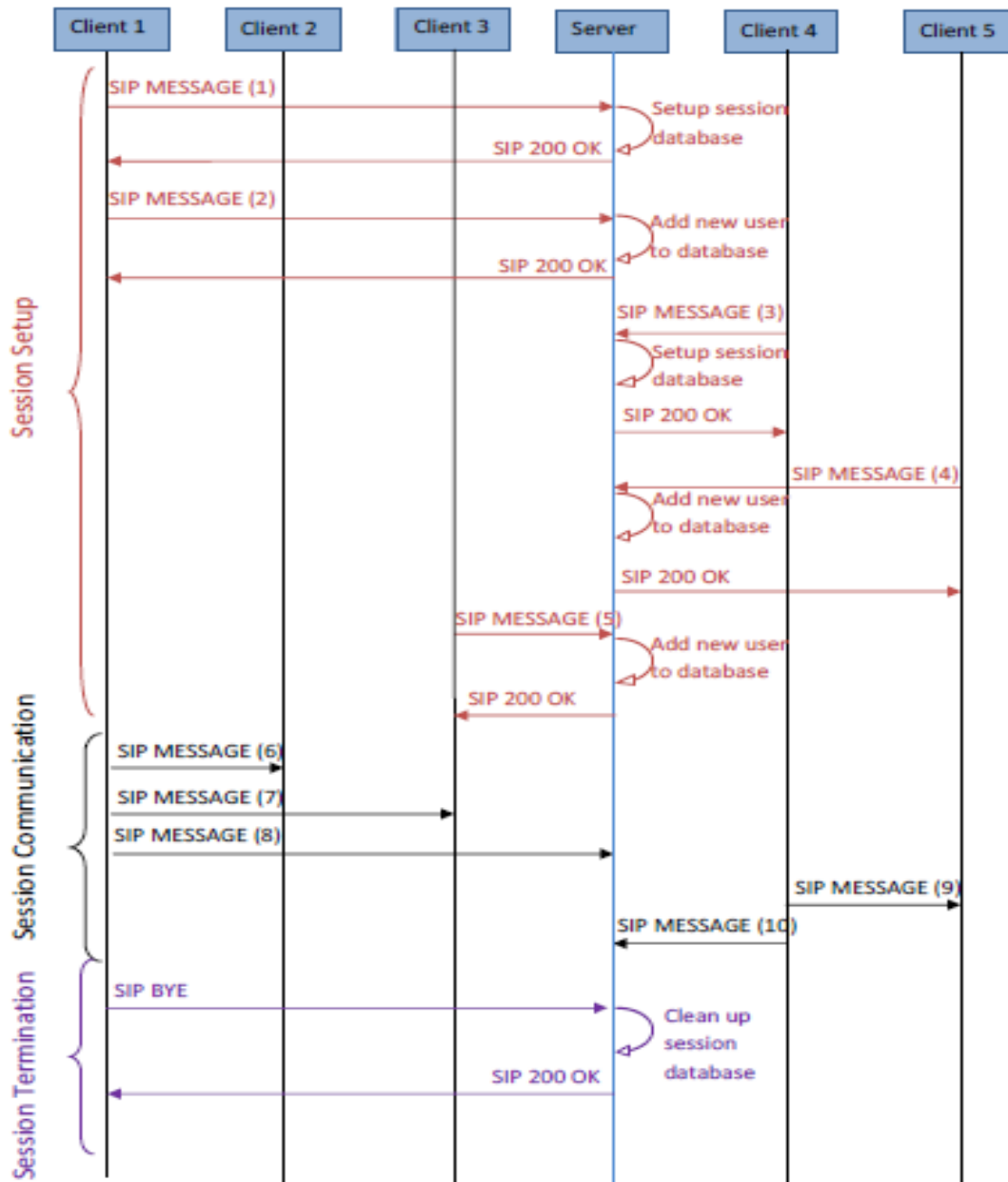
the session). When Alice receives this response, the voice call session is established. Voice data between the clients are sent via the Real-time Transport Protocol (RTP) specified in [65] while instant messages are sent over the Message Session Relay Protocol (MSRP) specified in [69].



**Figure 3.3 Client – Client and Client – Server communication**

Figure 3.3 shows how clients communicate with one another as well as with the server. The IMS core entities provide the required signalling in order to establish a virtual classroom session which includes the establishment of voice call sessions and instant messaging sessions among the participants. The shared whiteboard communication uses the instant messaging session established between clients to facilitate real-time updates of the individual participants' whiteboards. Instant messages intended for whiteboard updates, contained information describing objects drawn on the client's (sender) whiteboard. This information include: the type of object, location of the object on the whiteboard, colour and other properties of the object. The client (receiver) is required to process this information and reproduce the same object on its whiteboard in order to keep the two client whiteboards synchronized.

Although not shown in Figure 3.4 below, each client is required to register with the IMS core prior to accessing the virtual classroom service. Clients register by sending SIP REGISTER messages to the P-CSCF. After performing the necessary user authentication, a SIP 200 OK is sent to the user to confirm a successful registration. Note that all request messages to the server traverse through the IMS core CSCFs. This is not shown in the signalling diagram for simplicity.



**Figure 3.4 Signalling scenario of virtual classroom session**



Figure 3.4 presents a signalling scenario for a typical virtual classroom session. During the session setup phase, messages (1) and (3) from Clients 1 and 4 respectively, represent a server registration and virtual classroom initiation messages. When these messages arrive at the server, the server creates new Session Identification Numbers (SIDNs) which it attaches to a 200 OK SIP response. It further sets up the session database for the particular sessions, thus setting up two virtual classroom sessions in this case. The SIP 200 OK responses are sent to the initiators of the sessions to notifying them that the virtual classroom sessions have been successfully initiated. When the initiator receives the SIP 200 OK response, then virtual classroom session has been initiated.

Messages (2), (4) and (5) would represent a join-session message request from clients 2, 3 and 5 respectively after acquiring the SIDNs. For the purpose of this work, the server generates the SIDN based on randomly selected characters and digits. A SIDN number is made up of thirteen combinations of characters and digits giving an alphanumeric value. An example of a typical SIDN number would be *ay2hy3gh7qz0*. In order to enforce session security (allowing only permitted members to join a session) a session joining process was incorporated into the framework. The extra signalling required during the joining-session stage are omitted for simplicity. The session joining process is however outlined in Appendix A as it does not constitute a major aspect of this work. The work's primary focus is on shared whiteboard update communication.

When a new participant joins a virtual classroom session, each previous participant receives their user identity (SIP URI) from the server. Each participant uses this SIP URI to establish an instant messaging session with the new participant with regard to whiteboard updates and chat. The session initiator invites the new user to a multicast voice conference call by issuing a SIP INVITE with a session description SDP body attached. The receiver of the SIP INVITE may opt to accept this invite if it can support the specified requirements contained in the session description or decline it. The multicast voice conferencing is bidirectional, meaning all participants can speak and the others listen. Only one speaker is advised to speak at any given time to avoid many people speaking simultaneously.

Once the voice call and/or instant messaging sessions are established between the UEs involved, the IMS core entities are removed from signalling path allowing clients to communicate directly using the various media transport protocols (RTP and MSRP). Message (6) represent a virtual classroom session communication message, either a board-

update of something drawn on the whiteboard or an IM, between clients 1, 2 and 3. Message (9) represents a similar communication between clients 4 and 5 in the second virtual classroom session. Each participant sends SIP MESSAGES addressed to the various participants using their SIP URI. An example of a typical SIP URI would be *sip:alice@openims.testbed*. For logging purposes, messages (8) and (10) are sent to the server as well through the MSRP interface. Only text based communication data (whiteboard updates, instant messages) are logged at the server. Each client thus establishes an instant messaging session with the WAS.

To terminate the virtual classroom session, the originator sends a SIP BYE message to the server. After clearing that particular session's database, the server responds with a SIP 200 OK, acknowledging the successful termination of the virtual classroom session. The initiator further sends SIP BYE messages to all participants to end the voice and/or instant messaging sessions.

### **3.4 Chapter Discussion**

This chapter discussed the various requirements of a virtual classroom in the IMS. It further presents the proposed framework, required entities and lists some requirements of the implementation. The framework uses standard NGN and IMS entities, interfaces and protocols as defined by the 3GPP and ETSI TISPAN. These are IMS control functions, an application server and user equipment. As a result, service convergence and interoperability between vendor specific architectures is guaranteed. The chapter further presented the proposed IMS-based virtual classroom architecture.

The following chapters address the evaluation of this proposed architecture and how it performs with regard to real-time communication among virtual classroom participants.

# Chapter 4

## Architecture and Implementation of Evaluation Platform

### 4 Introduction

The previous chapter looked at the requirements of virtual classrooms based on reviewed literature before presenting a virtual classroom framework that to satisfy these requirements.

This chapter presents the objectives, requirements and limitations of the evaluation platform used to test the effect of the proposed framework on users' QoE of the virtual classroom service. The chapter further provides a brief description of the software used to implement the test-bed. Thereafter, the architecture and hardware elements of the test-bed are described. Full hardware and software specifications can be found in Appendix B.

#### 4.1 Evaluation Framework Objectives

The objective of the evaluation platform is to test the effect of the framework on user's QoE of the virtual classroom service, focusing on shared whiteboard communication.

User's QoE is evaluated by analysing service latency and service features. QoE is defined as the overall acceptability of an application or service, as perceived subjectively by the end-user [39].

*Service latency* refers to virtual classroom session communication end to end delay. This includes delays in the terminal, network and servers. This work focuses on shared whiteboard communication delay which includes processing delay on the client user terminal, network delay (transmission, propagation and processing) and processing delays at the server. It is assumed that the virtual classroom application will be deployed over a highly managed SDP which offers voice calling QoS guarantees in terms of data rates, delay and information loss. As a result issues pertaining to voice calls such as jitter and packet loss are

not considered. Service latency also refers to the delays incurred by a user when joining an existing virtual classroom session. It is necessary to measure this metric due to latency experienced by current commercial implementations [32, 37]. These commercial systems rely on emails containing links to the virtual classroom session setup by the initiator (facilitator). Participants click on this link to join the virtual classroom session. Notably, emails are an asynchronous form of communication (non-real-time), and the successful delivery of the email is not guaranteed. The proposed framework seeks to provide a real-time means for participants to join virtual classroom sessions. Hence the virtual classroom joining process is evaluated on real-time bases.

Lastly, service latency also refers to virtual classroom session setup delay. Due to the limited amount of time that a virtual classroom session is usually scheduled for session setup, joining of a session by participants and session communication delays should be kept at a minimum.

*Service features* refer to the features and their ease of use as expected by the user. These include virtual classroom session initiation, joining of an existing session, virtual classroom registration by role, role search for “experts” in a particular subject and user profile configuration to change user communication preferences (automatically answer voice calls, private conversations, selective whiteboard updates).

Furthermore, NGN/IMS networks are access network independent. User may access virtual classroom services using different access network technologies which may have diverse effects on end to end latency. The effect of access technologies on the proposed framework is further investigated.

## **4.2 Requirements of the Evaluation Framework**

In order to satisfy the objectives of the evaluation framework, a suitable test-bed architecture must be designed. The proposed framework must be integrated with an IMS framework to ensure session high service delivery over a managed platform. The IMS defines a large number of functional elements for legacy networks. Only those pertinent to the scope of this thesis form part of the test-bed implementation. Essentially an IMS core network, comprising core Call Session Control Functions (CSCF) and a Home Subscriber Server (HSS), is to be implemented to test the proposed framework. Such a core network should

support full IMS registration, session control and the provisioning of Application Servers (AS).

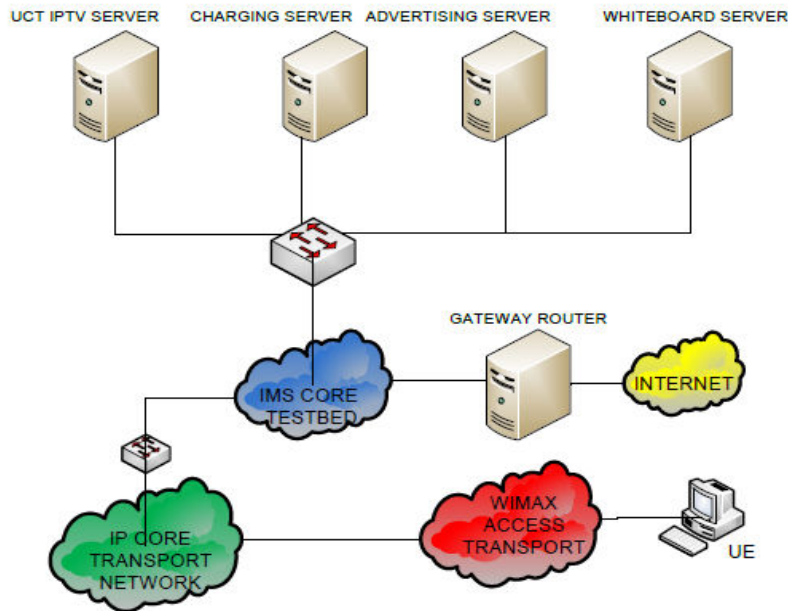
For the purpose of this thesis, a Whiteboard Application Server (WAS) is required in the application plane to intercept virtual classroom session requests originating from User Equipments (UEs).

UEs running an IMS client will be needed to register with the core network, initiate virtual classroom sessions and handle user interaction. The IMS client running on the UE should have a Graphical User Interface (GUI) for ease of use of the service features described in the previous section. These are the ability to initiate or join virtual classroom sessions; register with the WAS under a particular role and search for individuals based on these roles; and to modify user communication preferences (automatically answer voice calls, private conversations, selective whiteboard updates).

NGN/IMS networks are access network independent. This means that users may access the virtual classroom service using a myriad of access network technologies. For the analysis of the effect of access technology on the proposed framework, the test-bed must support multiple access technologies. For the purpose of this thesis, three access technologies are used in testing the effect of access technology on the proposed framework.

#### **4.3 Architecture of the Evaluation Platform**

The UCT IMS test-bed was used as the evaluation platform and modified to suit the evaluation requirements. The test-bed used is a prototype of the Next Generation Networks architecture, using IEEE 802.3 standard (Ethernet-LAN), IEEE 802.16 standard (WiMAX) and IEEE 802.11 standard (WLAN) as access technologies. The IMS core is used to provide sip signalling in the control layer. Internet Protocol (IP) routers interconnect the IMS core, access technologies (e.g. wireless router) and the application servers. For the purpose of this thesis, a Whiteboard Application Server (WAS) was added to the application layer to provide virtual classroom services. Figure 4.1 presents the test-bed architecture in the Communication and Research Group (CRG) lab at the University of Cape Town.



**Figure 4.1 UCT NGN/IMS test-bed prototype**

#### **4.4 Limitations of the Evaluation Platform**

Hardware test-beds are limited in size due to associated costs and limitations of the hardware required to construct the test-bed. Simulations are usually selected as the better option for testing scalability issues due to their inherent ability for system and user numbers to be scaled to amounts that cannot be practically implemented in a physical test-bed. However, simulations often do not take into account all real world factors (i.e. processing requirements of servers, accurate delay estimates, and other hardware factors). These delays are important when testing QoE as they add to service latency (discussed earlier). Hardware test-beds, however, allow for realistic analysis of service latencies and service features to be performed. Trends can be easily observed with a minimum number of entities that can be scaled up to draw conclusions on a large number. Furthermore, in order to test the service features mentioned earlier, a practical test-bed is required as both hardware and software play a role in testing these features.

Limitations exist in the operation of the test-bed due to time limitations. The operation of the test-bed differs slightly from that discussed in the proposed framework. These differences are discussed below. However, they do not have negative effect on the accuracy

of the evaluation, as there are no major differences between the theoretical framework, detailed in the previous chapter and that of the evaluation test-bed.

The session joining process deviates from the session joining process outlined in Append A. The session initiator issued the SIDN automatically. This was necessary in order to effectively measure session joining delays which involves processing delays (client and server) and network delays (transmission, propagation and processing). For testing purposes, the SIDN was issued automatically without the intervention of the session initiator (waiting for the initiator to accept the session joining request). Furthermore, the client was hard-coded to automatically choose the first session initiator after receiving a list of current session initiators. This again was for the purpose of removing human induced delays (waiting for the user to peruse the received list of initiators).

The UCT IMS Client presence feature required a Presence Server (PS) to be integrated with the framework. For the purpose of this thesis, the functionalities of the presence server were integrated with the Whiteboard Application Server (WAS) for reasons discussed earlier.

Furthermore, it would be better to store session communication data during a virtual classroom session in another logical entity in order to limit the amount of hard-drive space required by the WAS. For the purpose of this thesis, this functionality was integrated with the WAS for proof of concept testing.

## **4.5 Test-bed Components**

### **Call Session Control Functions and HSS**

The Fokus Open IMS Core [75] is used to provide all the necessary functionalities of the control plane in an NGN-type network. The IMS Core consists of a number of software programs to implement the three IMS CSCF (P-CSCF, I-CSCF, S-CSCF), as well as a HSS. The IMS Core is responsible for the routing of IMS SIP signalling between clients and the WAS. Developed by the Fraunhofer Fokus Institute, the IMS Core was released as an open-source software with the intent to create interest and further development of IMS technologies. Up to date it has an active support forum and has become popular for use in IMS test-beds, which makes it a reliable reference architecture to test with.

## **The UCT IMS Client**

The UCT IMS Client [73] is used to provide the user with all required client functionalities for the virtual classroom service, such as IMS registration, initiation or joining of virtual classroom sessions, communication with the WAS as well as with other clients and resource sharing (file uploading and downloading). The various UE running the UCT IMS Clients used one of three access technologies supported by the test-bed: LAN, WiMAX and WLAN.

The UCT IMS Client was modified in order for it to support virtual classroom sessions. The modifications are detailed below:

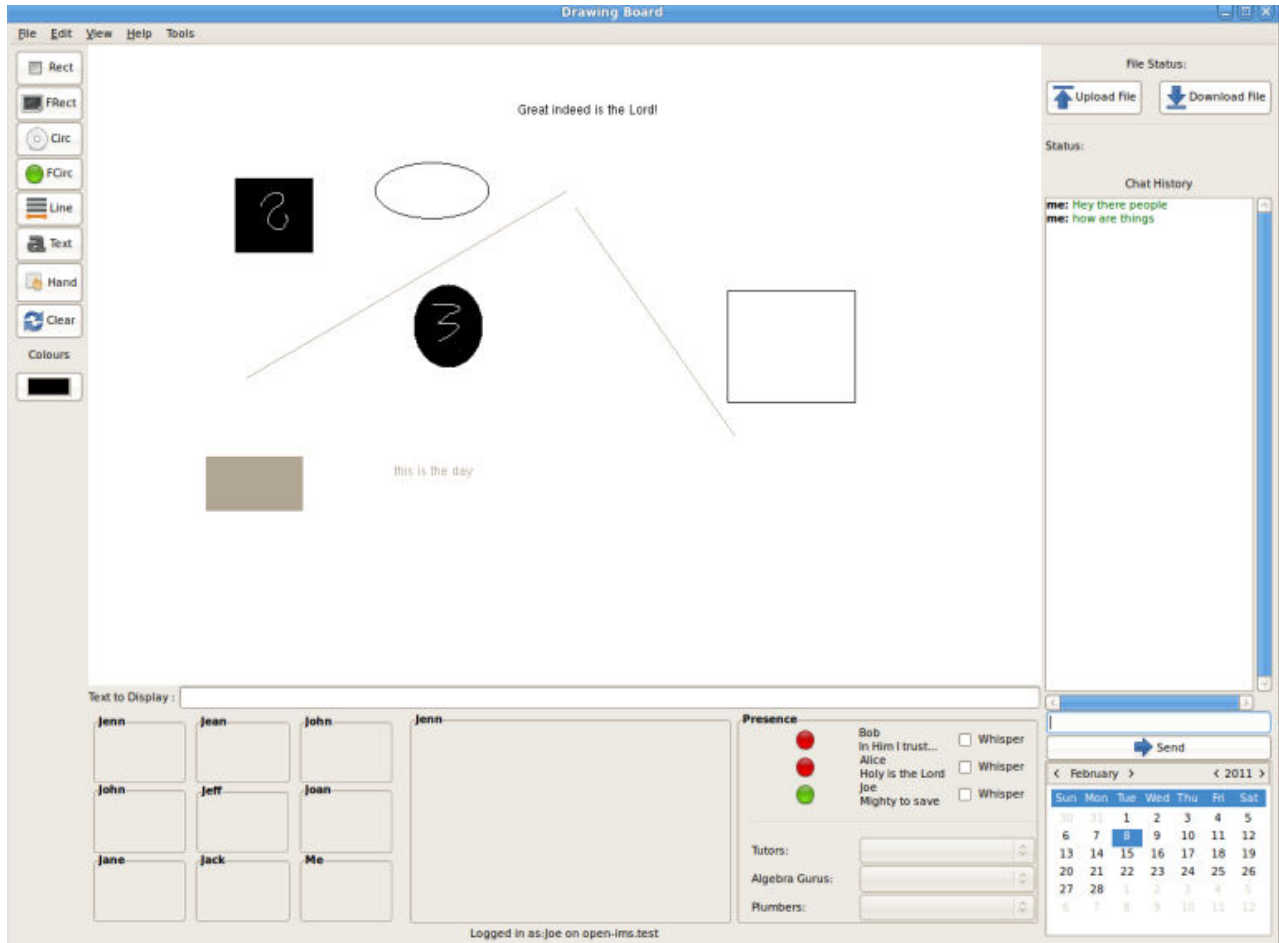
The UCT IMS Client is an open –source IMS client developed by students in the Department of Electrical Engineering, at the University of Cape Town. The client is written in ANSI-C and supports a number of functions including voice and video calling, instant messaging and presence. The client did not support virtual classroom services.

A shared whiteboard Graphical User Interface was developed using Glade User Interface Designer (GUID) together with GNU Image Manipulating Program (GIMP) Toolkit (GTK) library in C. For the purposes of this thesis, the whiteboard GUI only supports drawing of basic shapes (squares, rectangles, circles, lines, free-hand drawing) and text. The shapes and text can be drawn using different colours. labelled “whisper”, were provided. When “checked”, any communication (instant messages or whiteboard updates) sent from the client were sent to the selected individual. Multiple individuals could be selected to partake in a private conversation.

Figure 4.2 presents a schematic of the whiteboard GUI. Clients drew object by selecting an object type to draw (circle, square, etc) from the selection pane on the left of the GUI, then clicked a dragged from one point to another on the whiteboard space. Details concerning the object drawn were sent to the other clients engaged in that particular virtual classroom session. With regard to the free-hand drawing, the client collected a series of ten points prior to sending the details to the other clients. This was to minimize the number of messages sent while maintaining real-time communication among the participants of the virtual classroom session.



The whiteboard GUI provided the presence window, on which the presence status of participants was displayed. It further contained the instant messaging chat interface with support for group chat. In order to support private conversations, check buttons labelled “whisper”, were provided. When “checked”, any communication (instant messages or whiteboard updates) sent from the client were sent to the selected individual. Multiple individuals could be selected to partake in a private conversation.



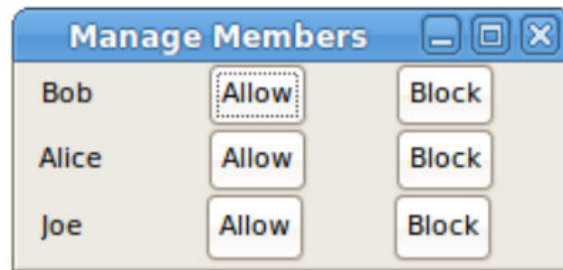
**Figure 4.2: The Whiteboard Application Client Graphical User Interface**

The UCT IMS Client GUI was modified to include virtual classroom specific action buttons (start session, join session). A user had the option to search for online virtual classroom users based on a specific role (e.g. tutor, algebra expert). To support this functionality, the UCT

IMS Client was modified to include a search action button. The results of the search were displayed on whiteboard GUI under the various roles.

Whiteboard updates from individuals could be blocked. This feature is particularly useful to prevent students from making unwarranted changes on the facilitators shared whiteboard interface. To achieve this, a “Manage Members” window was provided.

Figure 4.3 shows the GUI of the “Manage Members” window. The user can either “block” or “allow” whiteboard updates from other users to be displayed on their whiteboard GUI.



**Figure 4.3: User whiteboard update blocking page on IMS client**

### **The Whiteboard Application Server**

In the application plane, the Whiteboard Application Server (WAS) is used to provide the required virtual classroom setup functionalities. The WAS integrated a session database to store virtual classroom session communication data (IM-based messages only). The WAS did not have a GUI. It stored details of virtual classroom initiators in an array. The arrays contained initiators' IMS public user identity (IMPU). When the WAS receives a request from a UE, it analyses the request to indentify the type: a request to initiate a virtual classroom session; a request to join an existing session, a request to upload or download past session; a request to search for online users based on roles; or to terminate the virtual classroom session. Once the request type is identified, the WAS takes the necessary actions and generates an appropriate response. The clients embedded details of the request in an Extensible Markup Language (XML) encoded SDP body of the SIP MESSAGE to the server. Figure 4.4 presents an example of a request to initiate a virtual classroom session from the UE to the WAS. The client specifies “session” in the *type* tag of the XML document. It also specifies “start” in the *point1* tag.

```

MESSAGE sip:Alice@whiteboard.open-ims.test
SIP/2.0
  Via: SIP/2.0/UDP
137.158.125.251:5061;rport;branch=z9hG4bK5929141
67
    Route: <sip:orig@scscf.open-ims.test:6060;lr>
    Max-Forwards: 70
    From: "Alice" <sip:alice@open-
ims.test>;tag=1191155302
    To: <sip:Alice@whiteboard.open-ims.test>
    Call-ID: 2052264924
    CSeq: 1 MESSAGE
    Content-Type: application/sdp
    Content-Length: 18

```

#### Message Body

##### Session Description Protocol

```

<?xml version="1.0" encoding="UTF-8"?>
"<whiteboard
xmlns="urn:ietf:params:xml:ns:pidf"
  "xmlns:im="urn:ietf:params:xml:ns:pidf:im\
"
  <"entity="alice">
  <tuple id="UCTIMSClient">
  <alias>Ally</alias>
  <type>session</type>
  <point1>start</point1>
  ...
  ...
  </tuple>
  </whiteboard>

```

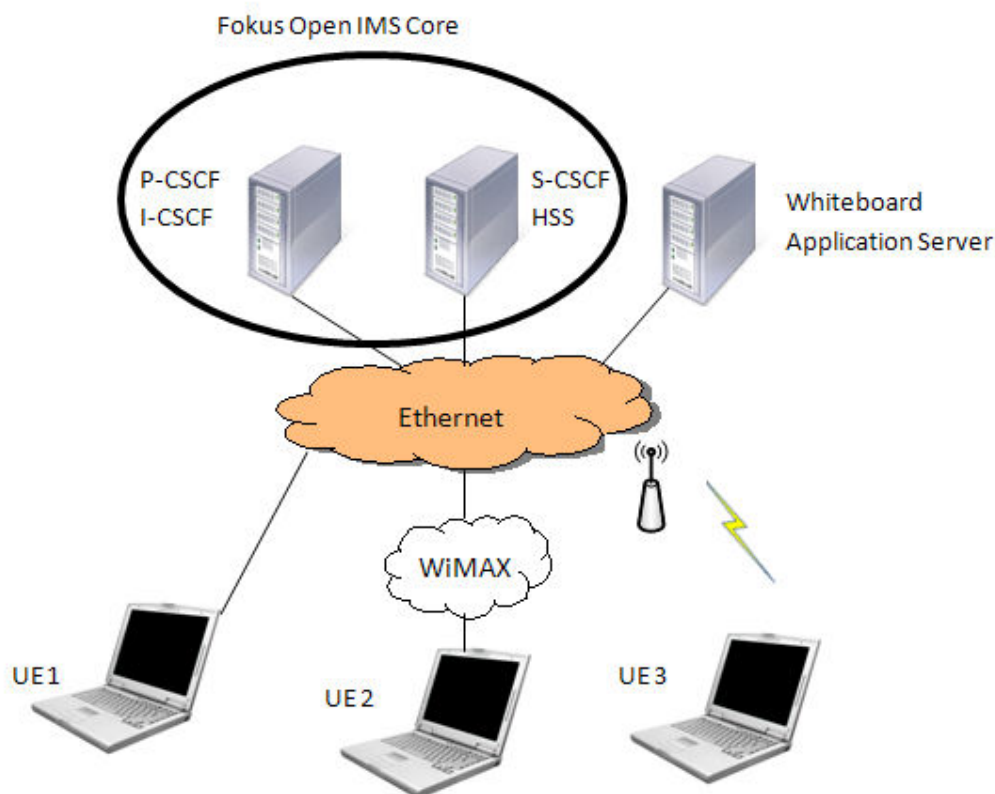
**Figure 4.4: Example of a XML encoded SIP MESSAGE SDP body**

The previous sections discussed the test-bed components and their various functionalities. The section looks at how these components were distributed in a practical test-bed.

## 4.6 Test-bed Hardware

The test-bed used comprised a number of computers. The specifications of these machines can be found under Appendix B. The four entities of the Fokus IMS Core were shared among two machines, with the P-CSCF and the I-CSCF running from one and the HSS and S-CSCF running on the other. Together, these two machines formed the Fokus Open IMS

Core. A third machine was used to host the application server, WAS. The other four machines were used to run the UCT IMS Clients which had been modified to support virtual classroom sessions as discussed in the previous section. The machines were connected using two switches and Ethernet cables. One of the client machines also hosted the Domain Naming Server (DNS) which assigned IP address to the individual machines. A wireless router was connected to one of the two switches to support wireless connections to the network. Figure 4.5 presents a schematic of the test-bed.



**Figure 4.5: Modified UCT IMS test-bed with virtual classroom support**

## 4.7 Chapter Discussion

This chapter outlined the design objectives of the evaluation framework presented in this thesis and discussed the requirements of the framework. The NGN test-bed used to test the application is discussed together with the necessary test-bed considerations to ensure the accuracy of the test results. The chapter further discussed supported features of the developed virtual classroom framework derived from current implementations and their

limitations. Details of the operation of the evaluation test-bed were presented. The results of the test run are presented and analysed in the following chapter.

# Chapter 5

## Results and Analysis

### 5 Measured Results and Analysis

The previous chapter presented the objectives, requirements and limitations of the evaluation platform used to test the effect of the proposed framework on users' QoE of the virtual classroom service. A physical test-bed was implemented to test the proposed framework.

This chapter presents and analyses the results of the set of test run on the physical test-bed. Two cases are considered with regard to the measured latencies based on the premise that not all users will be able to simultaneously support all the communication means (voice, IM, and shared whiteboard). To analyse the effects of access networks on the measured end to end delay, three access network technologies were used to test the proposed framework. The access network technologies used included IEEE 802.3 standard (Ethernet-LAN), IEEE 802.16 standard (WiMAX) and IEEE 802.11 standard (WLAN).

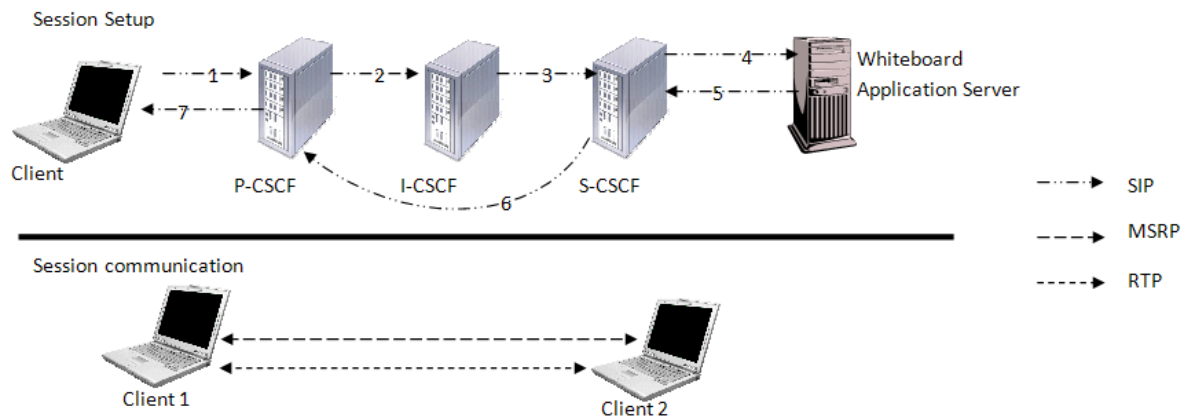
#### Test Scenario

Figure 5.1 shows the session setup process and session communication among virtual classroom participants once a virtual classroom session has been set up and participants have joined. A high level signalling diagram of the joining process will be discussed later. Session setup implements basic IMS service session setup. Requests from the client are routed through the IMS CSCF and are terminated at the application server. The application server responds to the requests which by-passes the I-CSCF and are terminated at the client terminal.

The test conducted involved 3 clients. One client initiated a virtual classroom session while the other two joined the session. Two test cases were considered during the testing process. In the first case only Instant Messaging sessions were initiated between the three clients. The reason for this is that the audibly impaired members of a virtual classroom session have no need for voice communication. Not all participants may have the necessary equipment

(microphone, speakers) to support voice calling at the time of the session. Further, voice data will require a higher bandwidth in order to be supported.

In the second case, the session initiator also invited each of the participants to a voice call. A virtual classroom session included the establishment of voice call sessions between the participants and/or instant messaging sessions between the participants. Instant messaging session was also used to facilitate whiteboard updates. Messages were sent over the MSRP interface. Voice data were sent over the RTP interface.



**Figure 5.1 Virtual Classroom session testing scenario**

### Tests Considerations and Limitations

The start time and end time of the measured end to end delay were obtained from different machines, specifically the originator and the receiver of the update message respectively. However, although the machines had synchronized clocks, using Network Time Protocol (NTP), they did not remain synchronized for longer than 2 minutes. This is attributed to hardware and software issues specific to the test-bed machines used. Some of the machines were older than others and used slower processors. Full specifications of the machines used are detailed in Appendix B. Occasional freezing of the machines were observed during the testing process. To keep the recorded times as accurate as possible, messages from the three clients had to be sent in a short space of time. This placed a limit on the number of messages that can be sent between the clients within 2 minutes. For the purpose of these tests,

messages were sent at an average rate of 1 message per second. An average of 30, 90 and 120 messages were sent between the three clients during the tests.

During the tests, end to end latencies were expected to adhere to human reaction time. The mean visual reaction time is in the range of 180 - 200 milliseconds [71]. With regard to this work the latencies experienced by the end user should fall within this range in order for them to be acceptable.

In order to get accurate measurements of end to end delays incurred during a virtual classroom session, it was imperative to synchronize the clocks of the different client machines on which the measurements will be taken. Synchronization of the machine clocks was achieved through the use of a network time synchronizing tool NTP. This tool uses an external server to synchronize network machine clocks. An *ntpdate* request was sent to server *ntp.ubuntu.com* for synchronization.

## **5.1 Evaluation of the Proposed Framework**

No benchmarks exist to compare the results obtained during the evaluation with regard to whiteboard update communication. Performance targets provided by bodies such as the ITU-T Study Group on QoS and QoE, specify targets for audio and video content [39]. Since instant messaging is used in this work to facilitate whiteboard updates, these performance targets are inappropriate. As a result human visual reaction time was selected as the benchmark to compare the results with regard to whiteboard update communication. Human visual reaction time is between 180 – 200 milliseconds. Virtual classroom service is a real-time service and communication among participants is expected to occur in real-time.

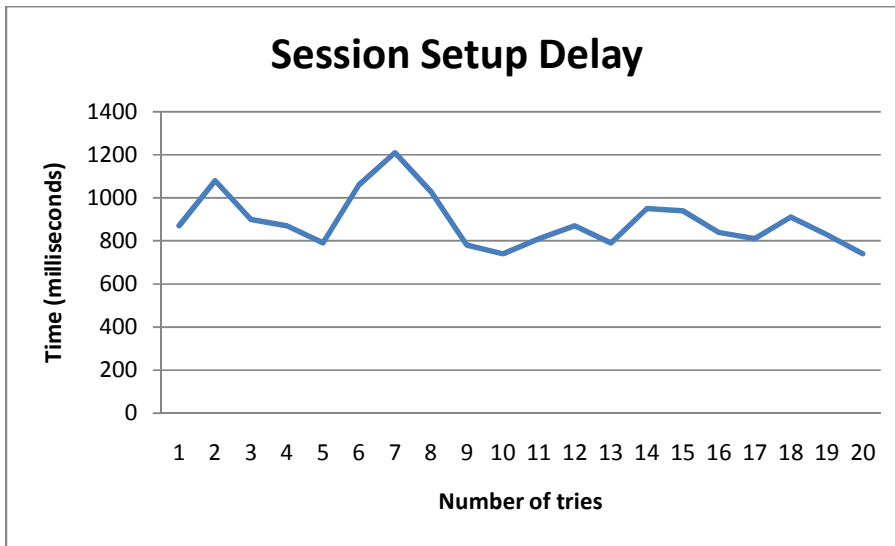
### **5.1.1 Service Latency**

This section presents an evaluation of service latency which includes: session setup delays, session joining delays and whiteboard communication delays during a virtual classroom session.



### Session Setup Delay

In order to measure session setup delay a typical virtual classroom request is initiated between a UE and the Whiteboard Application Server (WAS). The session setup up process requires the UE to send a SIP request to the WAS. The WAS sets up the necessary databases prior to informing the UE of the success or failure of the virtual classroom session initiation request. The server request was initiated 20 times and the session setup delay was recorded for each instance. Figure 5.2 graphically presents measured session setup delays and Table 5.1 presents a summary of these results.



**Figure 5.2: Session setup delay measurements for LAN access**

**Table 5.1: Summary of measured session setup delays**

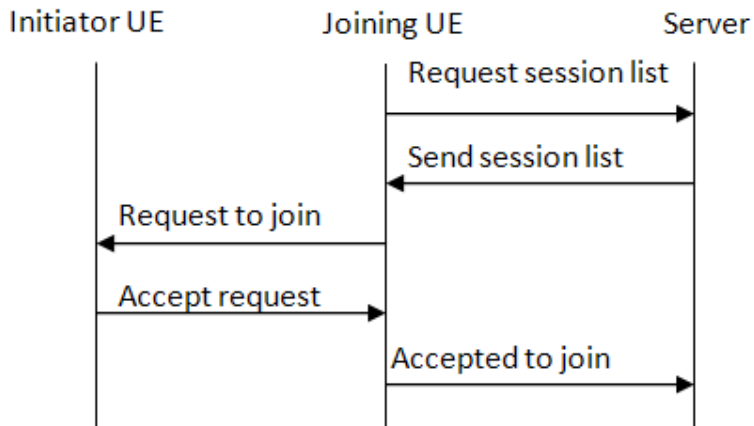
| No. Tries | Max. Delay (ms) | Min. Delay (ms) | Average Delay (ms) |
|-----------|-----------------|-----------------|--------------------|
| 20        | 1210            | 740             | 891                |

The average setup delay was found to be 891 milliseconds (0.89 seconds) which is not noticeable to the human eye. The maximum setup delay of 1210 milliseconds (1.21 seconds) can be considered tolerable for setting up a virtual classroom session. On aspects of scalability, session setup delays are bound to increase with the number of parallel sessions.

This is attributed to the server being required to deal with requests from more users simultaneously.

### Session Joining Delays

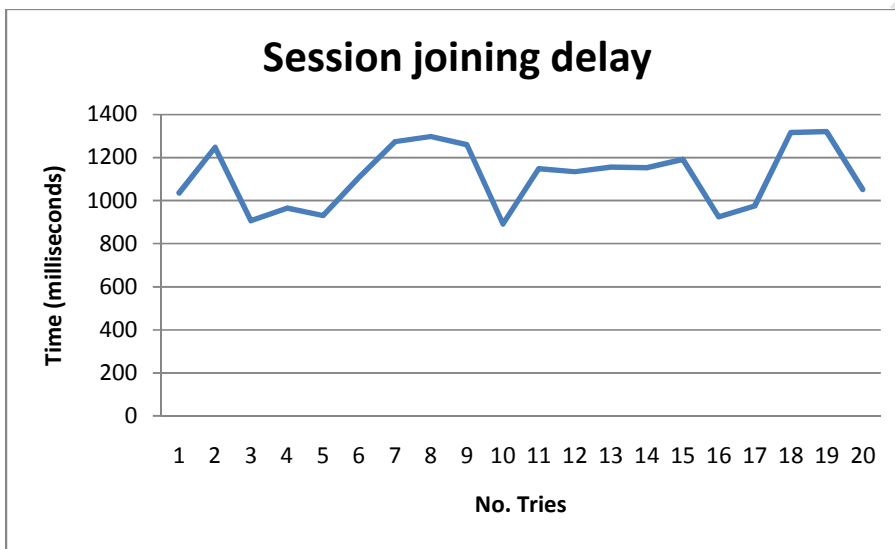
In carrying out session joining delay measurements, one UE was required to setup a virtual classroom session to allow a second UE to join that session. Joining of a virtual classroom session involves three parties: the session initiator, the server and the client requesting to join a session. The delays measured included client processing delays, network delays (transport, propagation and processing delay) and server processing delays. The Figure 5.3 presents a high level signalling diagram of the session joining process.



**Figure 5.3: Signalling diagram for joining a session**

The last stage (informing the server of the acceptance to join a session), is not included in the delay measurements but is shown for completeness. The UE requesting to join a session (requester) is considered part of the session after it receives the acceptance message from the initiating UE. The request to join a session to the session initiator is an invitation to an instant messaging session. The requester further specifies their media preference in the SDP body of the invite. The acceptance response to the requester is an acknowledgment to the invite. At this stage the initiator and the requester can engage in an instant messaging session for chat and shared whiteboard updates (which is facilitated by instant messages) as well as a voice call session. With voice calling invitations, media preference (e.g. supported codecs)

negotiations may require more signalling between the clients prior to the establishment of the voice call session. This will inevitably increase session joining delay. For the purpose of these tests, it is assumed that both the requester and the session initiator support the same media preferences and as a result no extra signalling is required. Two clients initiated a total of 20 session joining requests and the session joining delay was recorded for each instance. After each measurement (two session joining request, one from each client) the session was terminated and re-initiated. The process was repeated 10 times. Figure 5.5 presents a graphical representation of the measured delays while Table 5.2 presents a summary of the measured delays.



**Figure 5.4: Measured session joining delay**

**Table 5.2: Summary of measured delays when joining a session**

| No. Tries | Max. Delay (ms) | Min. Delay (ms) | Average Delay (ms) |
|-----------|-----------------|-----------------|--------------------|
| 20        | 1320.3          | 891.4           | 1114.5             |

## **Session communication Delay**

This section deals with virtual classroom communication, specifically whiteboard update, latencies during a virtual classroom session. Two cases are considered and are discussed below.

### ***Case 1: No Voice Sessions Between Participants***

This will typically be a case where one or more of the participants are audibly impaired and as a result have no need for audio communication. Another scenario where this will apply is when the users do not have enough bandwidth or the tools (microphone, speakers) to support audio communication and as a result rely solely on IM and the shared whiteboard to participate in a session. In this case no voice data are transmitted between the participants during the virtual classroom session. Only text-based instant messaging data are transmitted between the participants. End to end delay between client terminals, as depicted in Figure 5.1, are measured.

Figure 5.5, Figure 5.6 and Figure 5.7 present measured delays using the three different access technologies. The results are a measure of how long it took an object drawn on the screen of one client to appear on the other session member's screens. The user (drawer) selected an object to draw (rectangle, line, etc) from the selection panel and drew the object by clicking and dragging the mouse over the whiteboard interface. At the release of the mouse click, details concerning the drawn object (type of object, location on the whiteboard, etc) were sent to the other participants. The measured end to end delay is from the time the message is sent from the client (drawer) to it being reproduced on the other participant's whiteboard. Since two participants were involved, two measurements were recorded for each update message sent from the client (drawer). A varying number of whiteboard updates were sent from the three clients and the end to end delay was measures for each instance.

## LAN

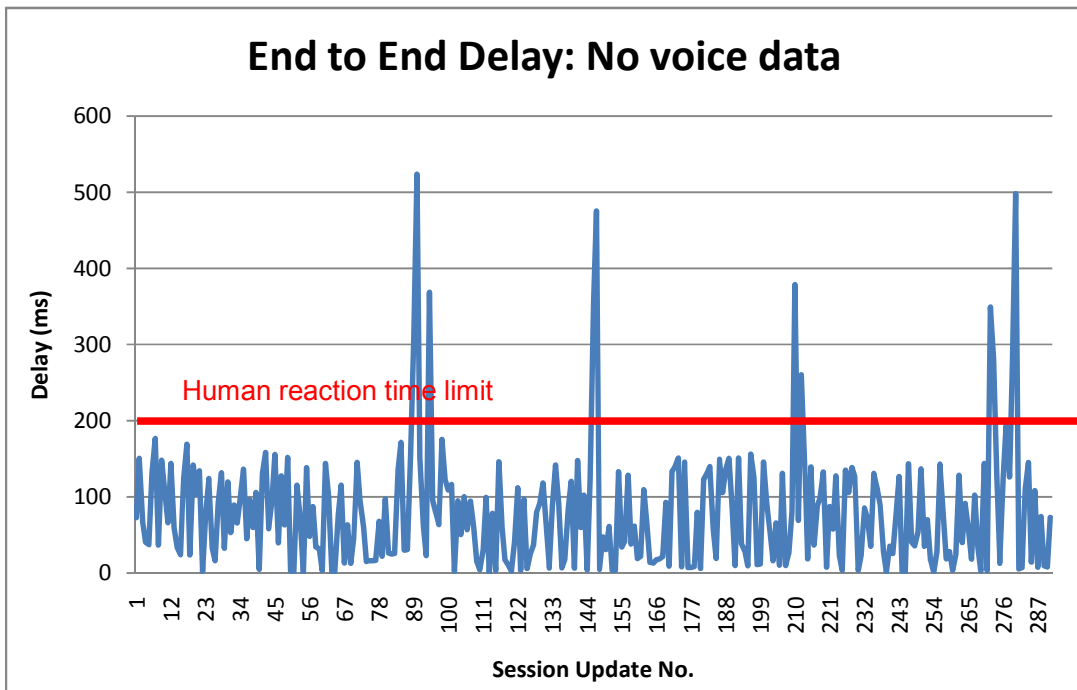


Figure 5.5 LAN: Measured end to end delays

## WiMAX

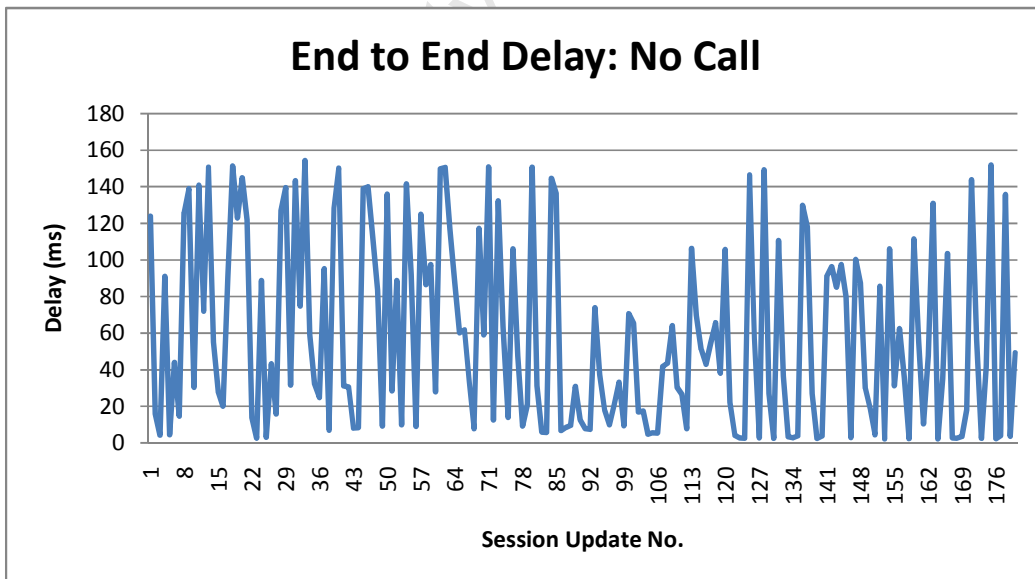
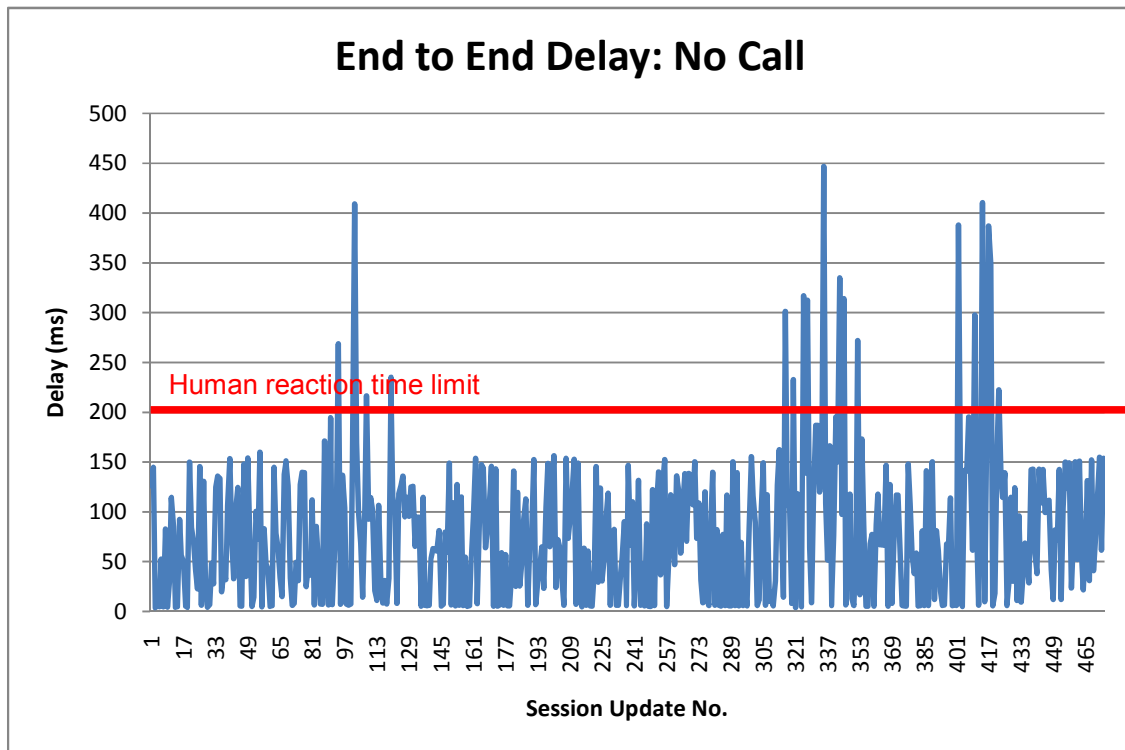


Figure 5.6 WiMAX: Measured end to end delays without voice conferencing

## WLAN



**Figure 5.7 WLAN: Measured end to end delays without voice conferencing**

### Discussion of Results

**Table 5.3: Peak analysis of whiteboard updates**

| Access Technology | Total No. Messages | No. Peaks | Percentage of late updates (%) | Ratio of late updates |
|-------------------|--------------------|-----------|--------------------------------|-----------------------|
| LAN               | 291                | 8         | 2.7                            | 1 : 37                |
| WiMAX             | 175                | 0         | 0                              | 0                     |
| WLAN              | 465                | 25        | 5.4                            | 1 : 18                |

In Table 5.3 we observe that not all messages sent between clients with regard to whiteboard updates are received within the specified human reaction time. Several peaks, 8 and 25, are

observed using two of the access networks, LAN and WLAN respectively. Considering the case of LAN access technology, the peaks result in an average of 2.7 % of the whiteboard update messages sent between clients arriving later than 200 milliseconds after they were sent. It is extrapolated that on average 1 in every 37 messages sent between clients will arrive late. The same analysis applies for the WLAN access technology. Using WiMAX access technology, however, no peaks were observed. This was not expected. However the lack of peaks can be attributed to possible low network congestion and the setup of the WiMAX prototype used. Specifications of the WiMAX prototype hardware can be found under Appendix B.

In all three cases, the percentage of updates that arrive late are minimal and can be considered tolerable for a virtual classroom application and thus will not majorly affect the users overall QoE of the virtual classroom service.

### ***Case 2: Voice Sessions Between Participants***

The second set of tests carried out were to evaluate the effect of voice conferencing on the virtual classroom application whiteboard updates. This is the case whereby participants are able to support voice conferencing (i.e. they have all the required equipment (speaker, microphone) and required bandwidth). The session initiator establishes voice call sessions between itself and the other two clients. Each voice call session is bi-directional, both the session initiator and the participants can speak and be heard. This case would be considered the more ideal case, where a teacher or session facilitator is able to communicate with session members using audio communication while graphically representing what they are saying on the shared whiteboard.

The establishment of a voice session between the participants means that voice data will be transmitted between the participants during the virtual classroom session. This will inevitably increase the delays with regard to whiteboard updates. In the first case discussed earlier, only instant messaging sessions were established between the participants.

The measured end to end delays presented in Figure 5.8, Figure 5.9 and Figure 5.10 were obtained in a similarly process to that described in the first case above. The only difference now is that voice data were also being transmitted between participants during the tests.

## LAN

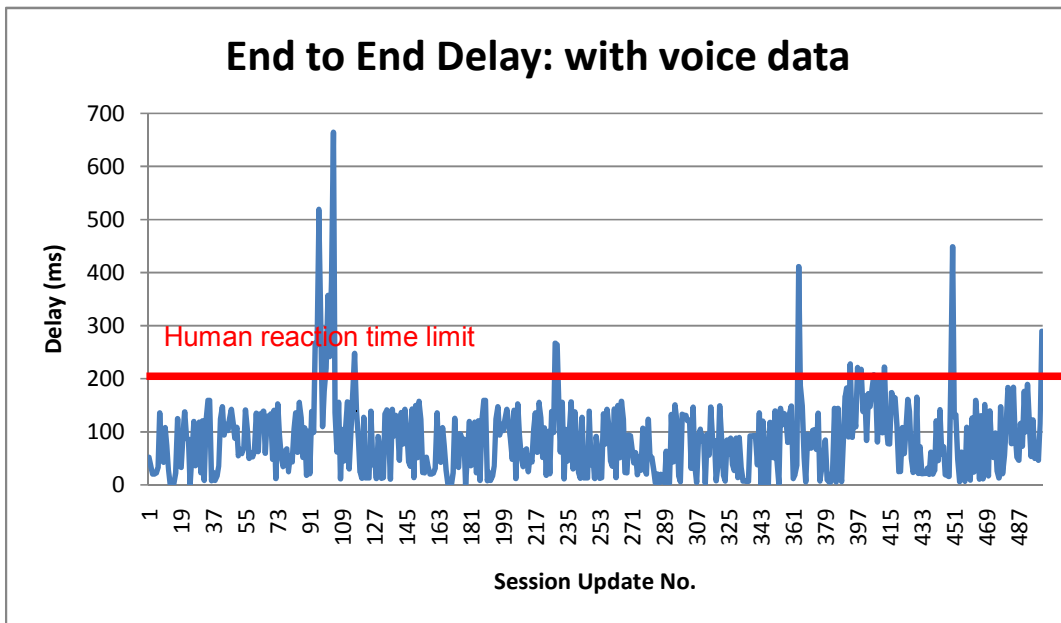


Figure 5.8 LAN: Measured end to end delays during a session

## WiMAX

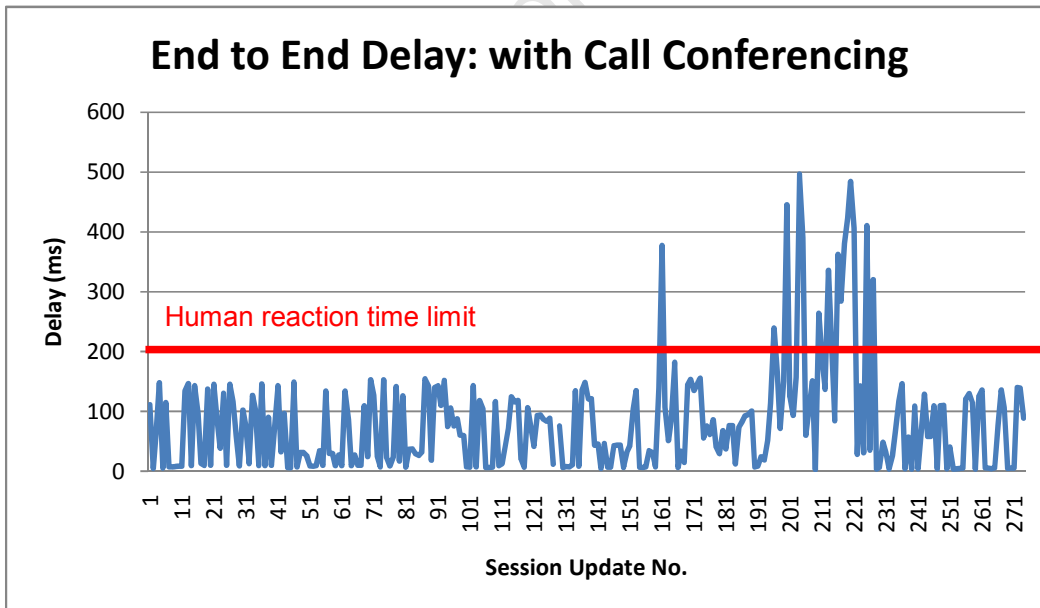


Figure 5.9 WiMAX: Measured end to end delay



## WLAN

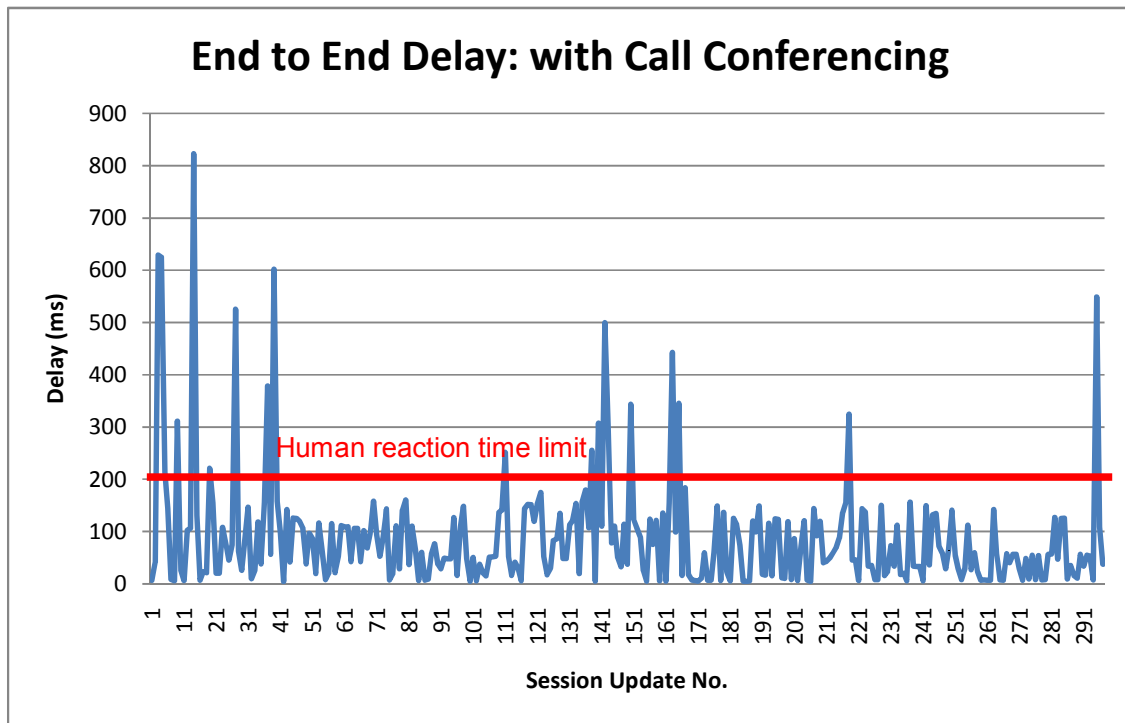


Figure 5.10 WLAN: Measured end to end delay

## Discussion of Results

Table 5.4: Peak analysis of whiteboard updates

| Access Technology | Total No. Messages | No. Peaks | Percentage of late updates (%) | Ratio of late updates |
|-------------------|--------------------|-----------|--------------------------------|-----------------------|
| LAN               | 494                | 13        | 2.6                            | 1 : 38                |
| WiMAX             | 271                | 10        | 3.7                            | 1 : 27                |
| WLAN              | 291                | 16        | 5.5                            | 1 : 18                |

In Table 5.4 we observe several peaks, signifying late arrivals of whiteboard update messages sent between the clients. Late in the sense that they took longer than 200

milliseconds to arrive at their destination. These peaks are attributed to network congestion during the test. Hundreds of whiteboard updates were sent between the clients during the testing process. In order to minimize the effect of network congestion, the servers and clients were restart after each round of tests. Eighty whiteboard update messages were sent on average between clients in each round.

For example, among the 271 messages sent between clients using WiMAX access technology, 10 peaks (late arrivals) occurred. This amounts to a total of 3.7% of the total messages sent. Based on this percentage, it can be extrapolated that 1 in every 27 messages sent between clients during a virtual classroom session will arrive later than expected. This however is a minimal percentage and can be considered tolerable for virtual classroom applications and will not negatively affect a users overall QoE of virtual classroom service.

### ***Comparison between the two cases***

In the first case we considered participants engaged in a virtual classroom session without voice conferencing. This means that no voice data were transmitted between the participants during the virtual classroom session. The second case considered participants engaged in voice conferencing, thus voice data were transmitted during the virtual classroom session. Adding voice communication to a virtual classroom session requires more bandwidth and as such delays were expected to increase. Table 5.5 presents measured average end to end delay with regard to the two cases.

**Table 5.5: End to end delay comparison: Case 1 and Case 2**

| <b>Access Technology</b> | <b>Case 1<br/>(ms)</b> | <b>Case 2<br/>(ms)</b> | <b>Difference<br/>(ms)</b> |
|--------------------------|------------------------|------------------------|----------------------------|
| <b>LAN</b>               | 80.0                   | 86.4                   | 6.4                        |
| <b>WiMAX</b>             | 58.3                   | 81.7                   | 23.4                       |
| <b>WLAN</b>              | 79.1                   | 87.7                   | 8.6                        |

The difference between the two cases ranges from 6.386 milliseconds to 23.261 milliseconds with regard to the three access technologies used during testing. The added delay further reduces the maximum number of students that can be supported per session while maintaining real-time communication among all participants. Further analysis of the scalability of the application is presented in section 5.2 below.

### Analysis of the effect of Access Technology

It is further observed in Table 5.5 that a user will incur different delays based on the access technology used to access the whiteboard application. With regard to the tests run, the user incurred almost the same delays when using the LAN and WLAN access technologies. The least end to end delays were found to be incurred when using WiMAX access technology. This applied for both Case 1 and Case 2 (with voice conferencing and with-out voice conferencing).

#### 5.1.2 Service Features

Figure 5.11 shows the user GUI of the UCT IMS Client.

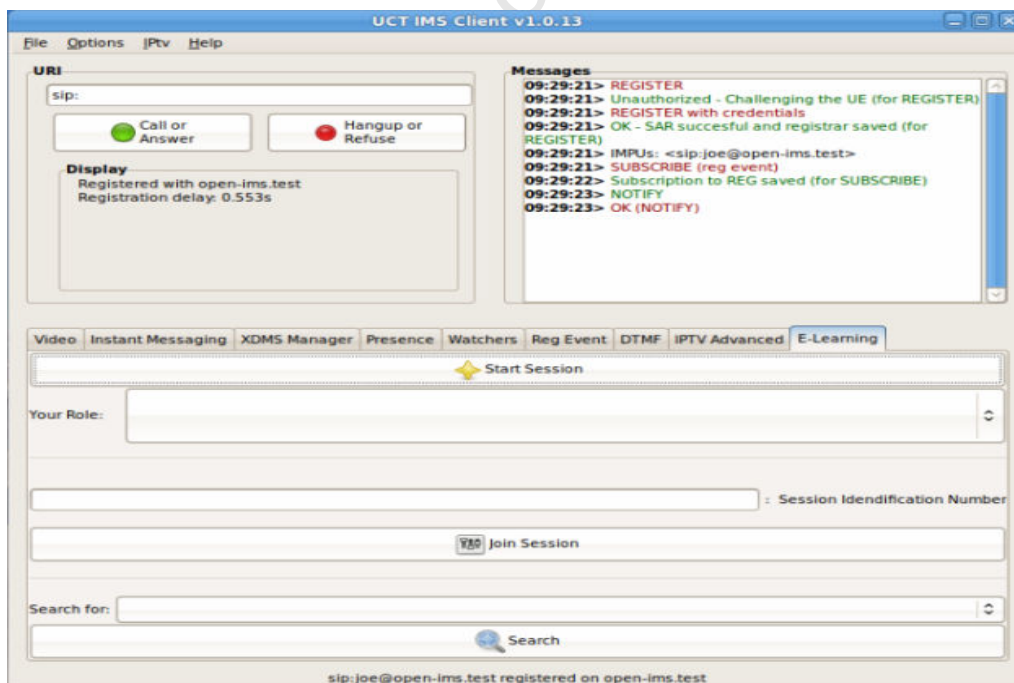









Figure 5.11: User GUI of the UCT IMS Client

User expectations determine the expected virtual classroom service features. A GUI is required, offering ease of use of the services such as IMS registration and virtual classroom session initiation and joining. A facilitator is able to easily register with the IMS and initiate a virtual classroom session from the drop down menus at the top of the client interface. The facilitator is able to easily initiate a virtual classroom session from the e-learning tab on the UMT IMS Client interface. Similarly, a user seeking to join a particular session can easily do so after registering with the IMS.

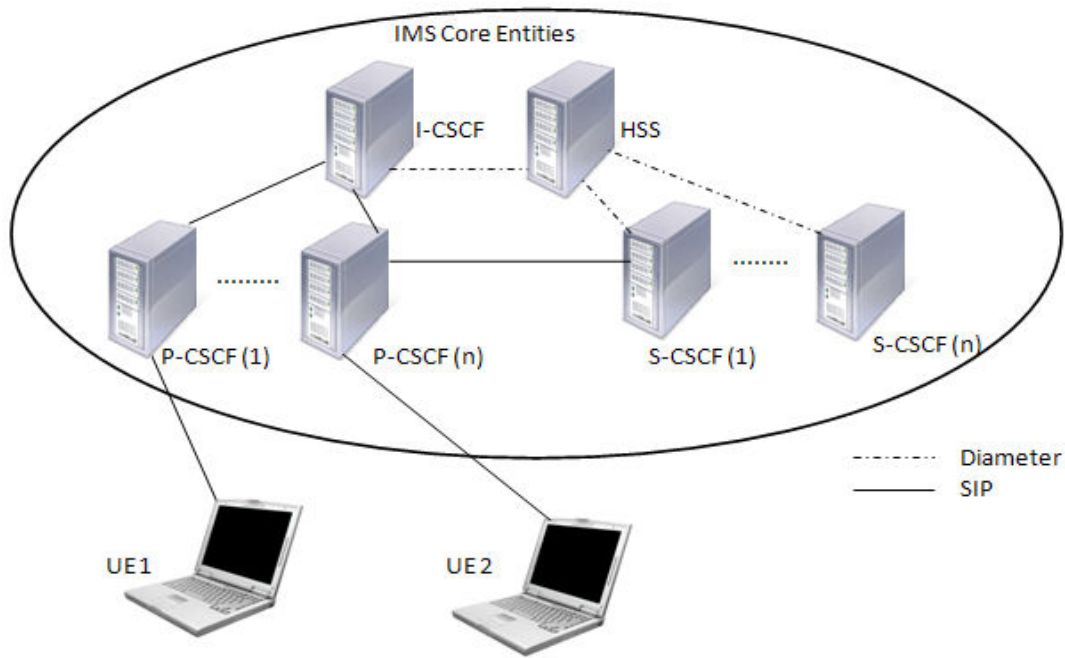
Features of the virtual classroom application client were outlined in section 4.5 under The UCT IMS Client. These client features ensured that user expectations of the virtual classroom service were met. These include virtual classroom session initiation, joining of an existing session, virtual classroom registration by role, role search for “experts” in a particular subject and user profile configuration to change user communication preferences (automatically answer voice calls, private conversations, selective whiteboard updates). Figure 4.2 showed the whiteboard application GUI with support for chat and shared whiteboard communication. Support for private conversations was provided. Users could block shared whiteboard updates from particular users as well as have private chats by selecting the “whisper” check boxes on the whiteboard application GUI. Figure 4.3 shows the “Manage Members” window on the whiteboard application GUI where a user is able to easily block whiteboard updates from other users. Table 5.6 presents the test results of the individual service features. The proposed framework successfully met all the requirements based on service features. These features contribute positively to user QoE.

**Table 5.6: Session features test results**

| Service Feature                        | Success or Failure   |
|--|--|
| Session initiation                     |   |
| Joining session                        |   |
| Virtual classroom registration by role |   |
| Role search for “experts”              |   |
| Automatic voice call answer            |   |
| Private conversations                  |   |
| Selective whiteboard updates           |  |

## **5.2 Scalability**

Due to hardware test-bed limitations discussed earlier, scalability tests could not be carried out. However, the IMS offers scalability through its ability to support multiple CSCFs. Figure 5.12 shows how multiple P-CSCF and S-CSCF can be hosted in an IMS network. This allows for multiple users to be serviced simultaneously. It assumed that scalability can be achieved through the use of multiple virtual classroom application servers dedicated to a set of users.



**Figure 5.12: Scalability of the IMS**

### 5.3 Chapter Discussion

This chapter presents an evaluation and analysis of the implementation based on service latency and service features. Service latency tests looked at session setup delays, session joining delays and session communication delays during a virtual classroom session. Two cases were considered during session communication. In the first case, participants were not engaged in a call conference and in the second case they were involved in a call conference. The evaluation was performed using three access technologies, LAN, WiMAX and WLAN. Table 5.1 presents a summary of the measured end to end delays for two cases using the above mentioned three access technologies.

The average incurred end to end delays was found to be below human visual reaction time, which is between 180 – 200 milliseconds, in all three access technologies. Several peaks were also observed, going above 200 milliseconds. However these were less than 6 percent of the overall number of messages sent between clients during the virtual classroom sessions. In the worst case scenario, this amounts to an average of one in eighteen (18) update messages arriving later than 200 milliseconds. The low ratio of late arrival of update messages will not majorly affect the users overall QoE and can be considered tolerable.

**Table 5.7 Average Whiteboard Communication Delay Results Summary**

| <b>Access Technology</b> | <b>Description</b>     | <b>Min Delay (ms)</b> | <b>Max Delay (ms)</b> | <b>Average Delay (ms)</b> |
|--------------------------|------------------------|-----------------------|-----------------------|---------------------------|
| <b>LAN</b>               | No call conferencing   | 0.1                   | 523.7                 | 80.0                      |
| <b>WiMAX</b>             | No call conferencing   | 2.1                   | 154.3                 | 58.4                      |
| <b>WLAN</b>              | No call conferencing   | 3.9                   | 446.6                 | 79.1                      |
| <b>LAN</b>               | With call conferencing | 0.6                   | 664.2                 | 86.4                      |
| <b>WiMAX</b>             | With call conferencing | 2.6                   | 496.8                 | 81.7                      |
| <b>WLAN</b>              | With call conferencing | 4.2                   | 822.9                 | 87.7                      |

Analysis of the effects of different access technology on end to end delay showed that WiMAX offered the least end to end delay with regard to whiteboard update messages. This again was unexpected. The low latencies experience using WiMAX are attributed to possible low network congestion and the setup of the WiMAX prototype used. Specifications of the WiMAX prototype hardware can be found under Appendix B.

# Chapter 6

## Conclusions and Future Work

### 6 Summary

Virtual classrooms provide an alternative platform for students to engage on an academic level. This thesis proposed and evaluated a virtual classroom framework over an IMS network. The application integrates voice conferencing, instant messaging, file sharing and a shared whiteboard to foster collaborative learning between students with or without a facilitator. It also investigates the current state of South Africa's communication infrastructure to support virtual classroom applications. The work further looks at the accessibility of students to computers needed to access virtual classroom service. Several ongoing projects were identified to be equipping schools with the necessary equipment.

The SADE has faced several challenges with regard to curriculum delivery including a shortage of teachers, educational resources such as textbooks and over-crowded classrooms. Virtual classrooms are emerging as alternative platforms for education besides the traditional classroom. Although commonly used for tertiary education course delivery, virtual classrooms hold potential to help curb some of the current challenges faced by the SADE. However, as real-time applications, current implementations have high bandwidth requirements and suffer from high latencies if the specified minimum bandwidth is not available. In South Africa the high cost of internet access leaves users opting for cheaper and thus slower internet subscription plans. These slow internet speeds cannot adequately support current implementations of virtual classroom services. The work presented in this thesis aimed to reduce the bandwidth requirements of virtual classroom applications in order for them to be widely adopted by users with low bandwidth internet connections. The work investigated the use of instant messages (text-based) to facilitate whiteboard updates. Due to the small size of instant messages, less bandwidth is required to transmit them.

The thesis proposed a framework that would allow network operators to easily integrate virtual classroom services to their existing networks. The proposed framework utilized standard NGN/INS components and interfaces to ensure this. A suitable evaluation platform



was used to test the effects of the proposed framework on the user's QoE. This was done by measuring service latency and service features. With regard to service latency: session setup delay, session joining delay and session communication delays were measured. A comparison between human visual reaction time and the obtained results was made. It was found that communication between participants during a session incurred delays below human visual reaction time of 200 milliseconds. However, certain peaks were observed in the obtained results at a maximum frequency of one per eighteen messages sent between participants. This amounted to an average of less than 6% of the messages, sent between session participants, arriving later than 200 milliseconds from the time they were sent. This low percentage of late messages can be considered tolerable and will not affect the user's overall QoE of the virtual classroom service.

The work further analysed the effect of access technologies on virtual classroom end to end delay between user terminals. Three access technologies, namely LAN, WiMAX and WLAN, were used to test the architecture. WiMAX was found to offer the minimum end to end delay.

## **6.1 Conclusion**

Based on the findings in the preceding chapters, the following conclusions are drawn:

- Virtual classroom applications consume bandwidth due to the multiple communication means (video, audio, and text) that they support in order to achieve full interactivity among participants. This is in-line with the original claims stated in literature. Using text messages to facilitate whiteboard updates reduced the bandwidth required to update whiteboards. Since text message packets are smaller, they require less bandwidth and can be transmitted quickly to facilitate real time communication. This thesis shows by proof of concept that such an approach to virtual classroom whiteboard updates can achieve effective communication among participants.
- Reducing the bandwidth required by virtual classrooms will essential open up the service to a larger group of users who were previously limited by slow internet access speeds.

- Having access to virtual classroom services will further allow schools and individuals to consider using virtual classroom services to supplement traditional classroom teaching.

## 6.2 Recommendations and Future Work

During the course of the work for this thesis a number of avenues for further research and applicability of the application emerged.

- WiMAX access technology offered the least end to end delay and as a result is recommended as the first preference for users who want to access virtual classroom application services.
- Video communication was out of the scope of this work. However it offers the user more interactivity during a virtual classroom session and as a result adding more value to the user's QoE. However it requires high bandwidth, which the general user may not be able to support. It would be interesting to investigate the use of video encoding schemes that minimize bandwidth consumption in the context of virtual classrooms. This can then allow video communication to be integrated into the application without compromising on real-time communication of the application.
- The whiteboard can be enhanced to support modern presentation styles such as the use of power-point slides and video screening. Slides can be converted into a series of images. Modern GUI interfaces support the displaying of messages in the text-fields, which is usually the whiteboard interface (drawing board). Participants will be required to download these images before the start of a session. Instant messages can then be used to specify which picture the client should load next as the facilitator pages through the slides.
- The interface of the application could be enhanced to make it more appealing to the target audience or tailored to suit different users. This can be achieved by using better GUI design applications that allow users to dynamically customize their own interface.
- More subject related tools can be added to the application to support the discussion of subjected specific problems. For example circuit drawing tools that facilitators could use when discussing topics like electricity.

- A recommendation system that suggests particular session facilitators based on the user's topic of interest could further enhance the users QoE. This can be achieved by incorporating a session facilitator rating system that allows session participants to evaluate the facilitator at the end of a session.
- Lastly, the role search feature could be extended to allow users to search for artisans such as plumbers, carpenters, electricians, etc. The artisans will need to register with the server as offering a particular service (carpentry, plumbing, etc). The server would then manage their presence as well as service user requests. For example if a user was searching for an electrician, the server will respond with a list of available electricians upon receiving the request from the user. The user can then contact the selected artisan directly after choosing one from the received list. The virtual classroom could then be used to discuss the problem that the user is facing, allowing the artisan to come more prepared.

# APPENDIX A

This appendix provides further details into matters discussed in Chapters 2 and 3.

## **Increased Bandwidth Availability**

As an important part of the New Partnership for Africa's Development (NEPAD) project, the East African Submarine Cable System (EASSy) spans twenty three coastal and land locked countries in East and Southern Africa [51]. This undersea cable holds potential to make telephone and Internet use more available and affordable for the African continent. The coastal countries included Sudan, Djibouti, Somalia, Kenya, Tanzania, Mozambique, South Africa and Madagascar. The other countries included Ethiopia, Lesotho, Uganda, Swaziland, Rwanda, Malawi, Burundi, Zimbabwe, Zambia, Botswana and the Democratic Republic of Congo. The completion of the cable will increase internet speeds significantly in South Africa to European and Asian countries.

The 9 900km long cable was initially poised to offer speeds of up to 320 gigabits per second and is part of a series of other cable projects such as SEACOM, GLO-1, TEAMS, MainOne and WACS [51]. However at its completion, the cable has a capacity of 1.4 terabytes per second (Tbps) [52]. This is a significant improvement from the 80 gigabytes per second bandwidth that was available to sub-Saharan Africa as recorded at the end of 2008 [53]. All the cables offer different bandwidth and serve the East, South or West coast of Africa. With such fast speeds and available bandwidth, questions pertaining to Africa's ability to fully utilize them arise. More web based services and applications will need to be developed to fully utilize the capacity and generate new revenue for Internet Service Providers (ISPs).

## **Equipment Required by Users to Access Virtual Classroom Services**

Besides the infrastructure, users need the necessary equipment such as computers in order to access the internet where virtual classrooms services are offered. The Third International Mathematics and Science Study (TIMSS) conducted by the Human Sciences Research Council (HSRC) in 1994 among 15 000 South African students, showed that South African students performed poorly in Mathematics and Physical Science compared to other

participating countries, including two African countries and several developed and developing countries. The students highlighted the lack of qualified teachers and the lack of equipment and facilities as contributors to their poor performance [5].

Several projects such as One Laptop per Child and the Tuxlabs initiative exist to address the issue of lack of computers in schools. Tuxlabs [2] which is sponsored by the Mark Shuttleworth foundation together with over 200 other school/community partnerships throughout South Africa aims to open up new opportunities and to encourage sharing of information and resources in the education sector. Using old personal computers, this project has enrolled over 100 schools in the Western Cape, 50 of which are connected through a wireless network. This wireless connection allows schools to communicate with one another and administrators to perform remote support. Students in schools have free network usage (internet browsing, emails, wikis, educator and learner chat groups, VOIP and IP security surveillance) but the labs are also opened to the general public after school hours for a minimal fee. The Tuxlab computers run a derivative of the open source Edubuntu and Xubuntu, called tuXlab GNU/Linux. Currently the project serves over 160 000 students and there are plans to integrate 50 more schools.

Furthermore, the Khanya Project is also playing a vital role in bridging the digital divide in the Western Cape region of South Africa [3]. Starting with the poorest of the poor schools, the Khanya project aims to restore racial and gender equity. The project provides schools with computer technology to be used as a teaching aid, hence improving curriculum delivery in South African schools particularly those of the Western Cape.

In the Gauteng province, Gauteng online is another project that aims to bridge the digital divide [4]. This provincial initiative aims to build a province-wide school computer network by creating 25-seat computer labs with internet and e-mail capabilities at all public schools in the province, to be used for curriculum delivery.

These ongoing projects, Tuxlabs , Khanya and Gauteng Online, together with several companies such as Microsoft, Telkom and Eskom have managed to equip schools with computers and Internet access. However, more needs to be done to connect students to other students through the use of the equipment provided by these projects.

It is clear that students are gaining access to computers with internet access. More students are expected to gain access to computers with internet access within the next year.

### **The role of ICT in Education**

A need to incorporate ICT in education, thereby providing alternative platforms to better foster learning anytime and anywhere, was proposed by the South African Department of Education (SADE) [12]. Connecting education with ICT is on intercontinental, continental, regional and national levels [19]. Numerous developed and developing countries are successfully integrating ICT into their education sector among which is the New Partnership for Africa's Development (NEPAD) initiative. This initiative aims to connect schools across its member countries, provide teachers with ICT skills to enhance teaching and learning and to provide school managers with ICT skills to facilitate better administration of schools. ICT has bridged the gap between students and information residing on the internet. Students no longer have to rely on teachers and textbooks alone. However, ICT should be seen as a tool or platform to support education and not as an end in itself.

ICT is currently being used to accelerate the attainment of teaching and learning goals, particularly in developing countries. Research into the development of innovative ICT applications to support teaching and learning in schools is ongoing. One such is by the Meraka Institute's ICT in Education Research Group (MI ICT ERG) [20] which aims to influence and support the transformation of education in South Africa, with a goal of each child benefiting from an environment where technology is embedded into learning and teaching. Meraka Institute's ERG has embarked on several projects including Mobileb, Young Engineers Programme and Tekkie Tots [20] to this effect.

### **Student Centred Learning**

Traditional learning methods have been around for centuries and have not evolved much over the years. This traditional learning method requires students to be at a specific place for specific amount of time. Having to be at a specific place for a specific amount of time may however not be ideal for students in their higher level of study, who need to maintain some form of income while pursuing their education. Technology has opened new doors of opportunities which are yet to be evident in the education sector and more so in the conventional way that students are taught or learn in general. Young people today are becoming more and more techno-savvy and this new avenue of learning is yet to be fully

exploited. Literature has proven that students learn more when they are actively engaged in the learning process [21] [22] [23]. Technology enabled learning methods require students to actively engage with the technology being used to deliver the lesson allowing them to actively engage with the learning material in one form or another.

Furthermore, giving students the freedom to choose when, where and for how long they study will better suit “modern” students at all levels and places students at the centre of their learning. Placing students at the centre of their learning can be achieved through the use of ICT with applications such as virtual classrooms if it is harnessed properly. Recorded classroom sessions, served as on-demand sessions, allow students to review sessions at their own leisure as many times as they want. Whereas, in traditional learning, if one misses a class session, they have to do their own extra work to catch up which many fail to do.

Studies have shown that people have different styles of learning [70]. There is a growing need to move away from the conventional lecturer/teacher to facilitators, who facilitate the learning of students. A facilitator in this context refers to a specially trained individual who helps students go through a given material of study.

Another area of concern is the student to teacher ratio in South Africa which is currently high in comparison with other schools in other countries, sitting at roughly 32:1 in public schools and 17:1 in private schools [24]. Statistics show that most schools in developed countries like America have ratios of 15:1 in public schools and as low as 9:1 for private schools [25]. Classes with a high student to teacher ratio often prove to be more disruptive to education. Having so many students in a given class inevitably results in a diverse group of students and less individual attention per student. The classroom dynamics become less obvious in such instances. High teacher to student ratio results in the “weaker” students getting weaker if a teacher goes through material too fast or the more able ones losing out if the teacher slows down to accommodate the slower learning students.

Virtual classrooms will help reduce the effect of such a situation by allowing students to study at their own pace. The slower students will have access to the material (recorded classroom sessions) even after the formal class session as either an audio playback or even video, if the session is recorded. This flexibility gives the “weaker” students the chance to catch up with the rest of the class. It also has the added benefit of not holding back the more competent students.

Furthermore, research has shown a gradual move towards a self study approach when considering the emergence of several online universities. Students are becoming more capable and more knowledgeable at far younger ages. The worldwide technological boom of the 21st century has seen children gaining access to information using mobile devices and personal computers where one is available. This access to information on the internet allows them to get information concerning topics of interest to them, placing them at the centre of their own education.

### **IMS Security**

This section presents some detail into the security features of the IMS. As previously mentioned, security is a concern with collaborative applications such as virtual classrooms due to the sensitive or personal information that participants may share with one another during a session. A typical example is when a company is having a private meeting with clients where delicate information is shared concerning a particular project. With regard to virtual classrooms, security is a major factor which affects the widespread acceptance of the application.

Two types of security techniques can be identified with regard to virtual classrooms; *general security* and *session security*. *General security* refers to the prevention of third parties from gaining access to information about a virtual classroom session by intercepting packets between session members. Not all sessions are public property since students pay to gain access to them. Session security refers to the prevention of third parties from joining a session that they are not allowed to.

The IMS, however, is significantly secure as it implements security at two levels of the Open Systems Interconnection (OSI) Network Model; access security specified in [40] and network security specified in [41] which is depicted in Figure below. The IMS uses IPsec [42] for both of its security schemes.

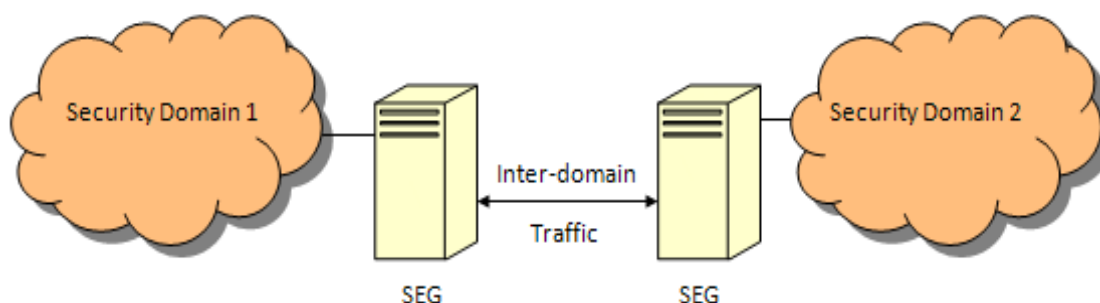
Access security involves user and network authentication as well as protection of the traffic between the IMS terminal and the network [43]. Access security in the IMS reduces the chances of third party users eavesdropping on a virtual classroom session.

In the IMS, a user has to be authenticated and authorized before they can use any of the available services. Post authorization entails users to two IPsec security associations. These



associations are used to protect SIP traffic between the user's IMS terminal and the P-CSCF. Having two security associations, instead of one, permits terminals and the P-CSCFs using User Data Protocol (UDP) to receive responses to requests on different ports other than the ones used to send the requests. 3<sup>rd</sup> Generation Partnership Project (3GPP) standardized the multi-port solution because of the solution's efficiency when compared with the single port solution. User authentication and authorisation is performed by the S-CSCF which downloads the authentication vectors from the Home Subscriber Server (HSS). The user also authenticates the network during the authentication process to ensure that they are not communicating with a falsified network. The afore mentioned security feature of the IMS provide the necessary session privacy required by virtual classrooms.

Network security, on the other hand, includes protecting traffic between network nodes belonging to the same or different network operators and/or providers. Considering the case where by the S-CSCF and the P-CSCF are in different networks, the exchange of traffic will be between different domains. Incoming and outgoing traffic pass through a Security Gateway (SEG). Figure 2.2 depicts such a scenario.

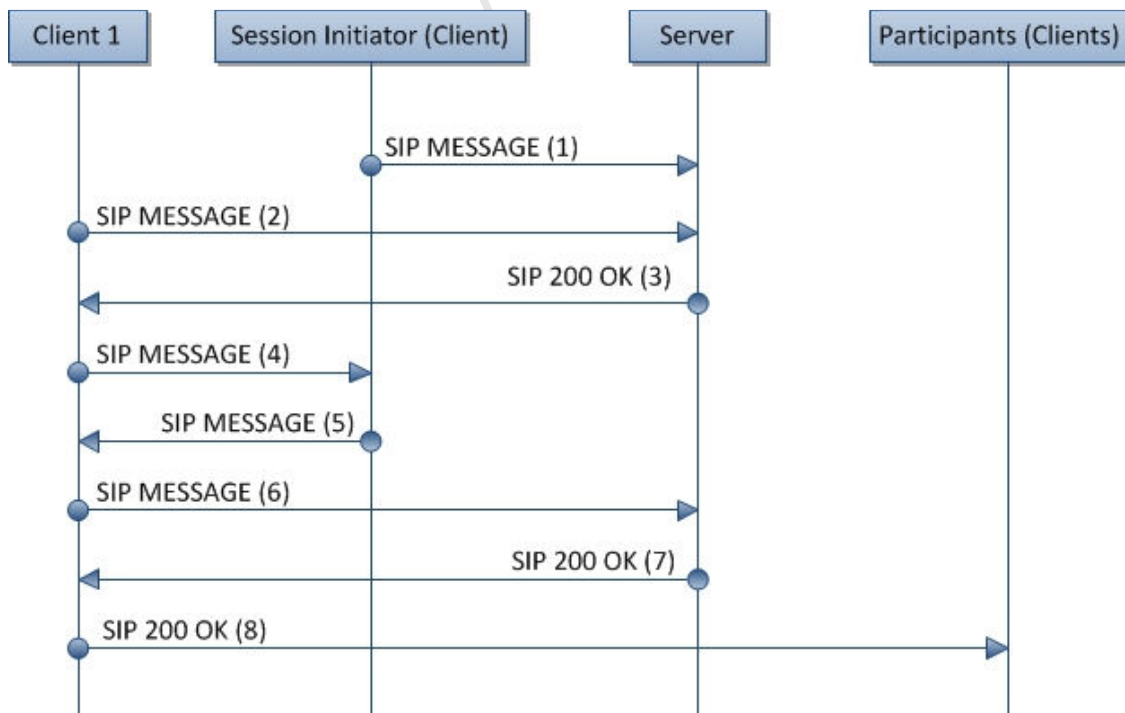


**Figure A.1 IMS Inter-domain security [43]**

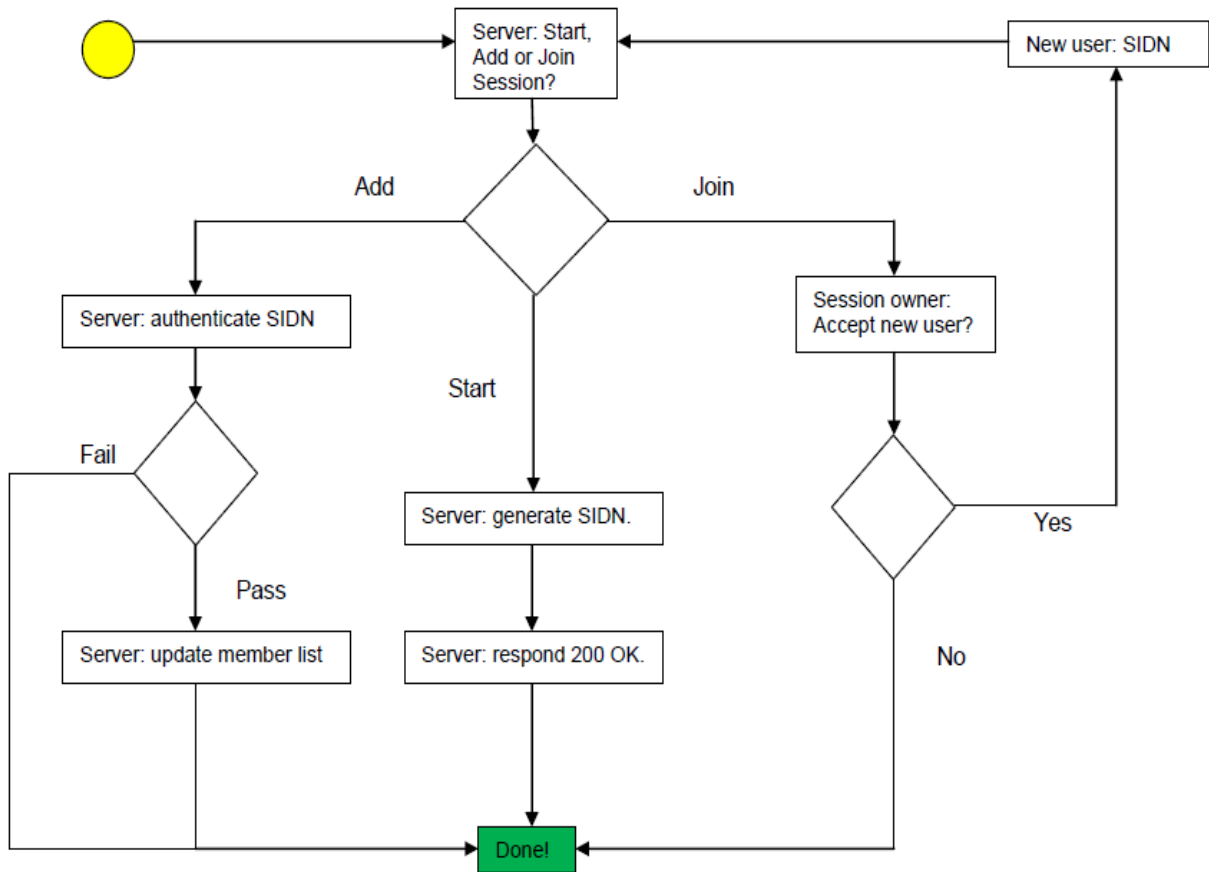
As traffic traverse between SEGs, it is protected by IPSec Encapsulated Security Payload (ESP) specified in [44]. The Internet Key Exchange (IKE), specified in [45], is then used to establish and maintain security associations between SEGs.

## Virtual Classroom Session Joining Process

Session privacy was implemented using the SIDN Scheme discussed in section **Error! Reference source not found.** With this implementation a user is only allowed to join sessions which they have permission to. A user first sends a request to the server for a list of currently available sessions. The server responds with a SIP 200 OK with a list of available sessions and the contacts (SIP addresses) of the session initiators. The user peruses the received list of currently available sessions and selects one to join. The request to join a session is then sent to the session initiator who can either accept or decline the request. If the session initiator accepts the user, they respond directly to the user with the SIDN attached to the response. Upon receiving the response from the owner, the new user sends a “Join Session” message to the server with the received SIDN. The WAS then updates its table of members belonging to that session and responds with a SIP 200 OK with a complete list of session members attached. The new member contacts the rest of the session members directly through board-updates. Each member then updates their session participants accordingly as they receive the messages from the new member. Figure 0.1 shows the signalling between the various entities and Figure 0.2 presents a detailed flow diagram of the activities.



**Figure 0.1 SIP Signalling: Joining a session**



**Figure 0.2 Flow diagram: Joining a session**

# APPENDIX B

## 1 Access Network Technologies

### 1.1 802.16 (WiMAX) Hardware Specifications

The WiMAX access technology used in testing has the following specifications:

- BreezeMax Micro Base Station ( $\mu$ BST) Indoor Unit (IDU) (Product number: BMAX-MBST-IDU-2CH-AC-3.5).
- BreezeMax Base Station Outdoor Unit (ODU) with connector for separate antennae (Product number: BMAX-BST-AU-ODU-2CH-3.5a1).
- BreezeMax Data Bridge IDU (Product number: BMAX-CPE-IDU-1D).
- BreezeMax CPE PRO ODU with connector for separate antennae (Product number: BMAX-CPE-ODU-PRO-SE-3.5).
- 3 X Agilent 30 decibels (dB) fixed attenuators (Product number: 8495A-001).
- Agilent manual step attenuator 0-70dB (Product number: 8491A-030).

Figure A.1 presents the WiMAX test-bed platform at the University of Cape Town (UCT) Communication and Research Group (CRG) laboratory. The client machines connected to the WiMAX equipment via LAN. The system operated in the 3.5 GHz frequency band as a result Radio Frequency (RF) cables were used to facilitate the air interface.

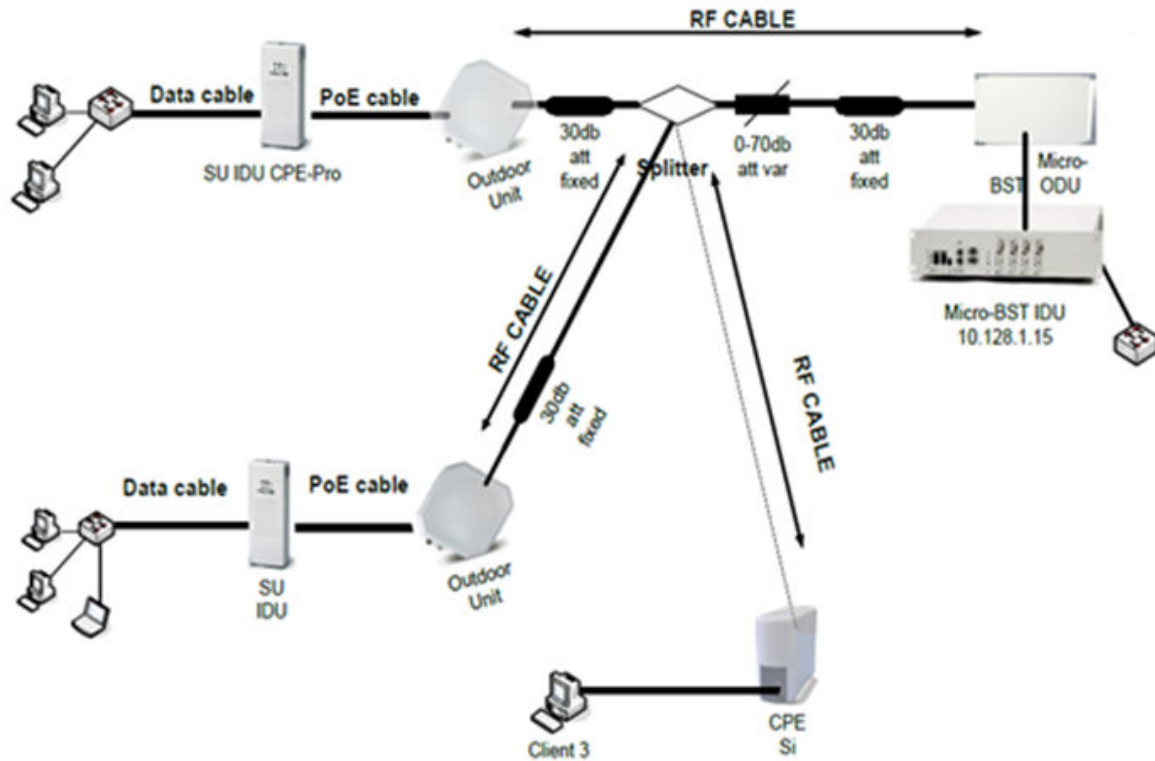


Figure B.1.1: WiMAX access technology prototype

## 1.2 802.11 (WLAN)

Full technical specifications of the wireless access point used can be found at [76].

## 2 HARDWARE

This appendix gives the details of each machine used in the test-bed architecture. The information was obtained using the following commands in ubuntu:

1. `head /proc/cpuinfo`
2. `head /proc/meminfo`
3. `lsb_release -a`
4. `uname -a`

### **I-CSCD and P-CSCF**

processor : 0  
vendor\_id : GenuineIntel  
cpu family : 6  
model : 23  
model name : Pentium(R) Dual-Core CPU E5300 @ 2.60GHz  
stepping : 10  
cpu MHz : 1203.000  
cache size : 2048 KB  
physical id : 0  
siblings : 2

MemTotal: 2052412 kB  
MemFree: 1084172 kB  
Buffers: 189832 kB  
Cached: 418996 kB  
SwapCached: 0 kB  
Active: 642364 kB  
Inactive: 209540 kB  
Active(anon): 307320 kB  
Inactive(anon): 8 kB  
Active(file): 335044 kB

Distributor ID:Ubuntu

Description: Ubuntu 9.04  
Release: 9.04  
Codename: jaunty

Linux imsuser-desktop 2.6.28-19-generic #64-Ubuntu SMP Wed Aug 18 20:55:57 UTC  
2010 i686 GNU/Linux

## **S-CSCF and HSS**

processor : 0  
vendor\_id : GenuineIntel  
cpu family : 15  
model : 2  
model name : Intel(R) Pentium(R) 4 CPU 3.00GHz  
stepping : 9  
cpu MHz : 2992.687  
cache size : 512 KB  
physical id : 0  
siblings : 2

MemTotal: 1016500 kB  
MemFree: 137952 kB  
Buffers: 207768 kB  
Cached: 242980 kB  
SwapCached: 0 kB  
Active: 422796 kB  
Inactive: 256116 kB  
HighTotal: 113852 kB  
HighFree: 224 kB  
LowTotal: 902648 kB

Distributor ID: Ubuntu  
Description: Ubuntu 8.10  
Release: 8.10  
Codename: intrepid

Linux imscore 2.6.27-11-generic #1 SMP Thu Jan 29 19:24:39 UTC 2009 i686 GNU/Linux

## **Server Machine and Client terminal 1**

processor : 0

vendor\_id : GenuineIntel  
cpu family : 15  
model : 3  
model name : Intel(R) Pentium(R) 4 CPU 3.20GHz  
stepping : 4  
cpu MHz : 3191.994  
cache size : 1024 KB  
physical id : 0  
siblings : 2

MemTotal: 1016500 kB  
MemFree: 182020 kB  
Buffers: 195684 kB  
Cached: 256140 kB  
SwapCached: 0 kB  
Active: 436024 kB  
Inactive: 215388 kB  
HighTotal: 113852 kB  
HighFree: 224 kB  
LowTotal: 902648 kB

Distributor ID:Ubuntu  
Description: Ubuntu 8.10  
Release: 8.10  
Codename: intrepid

Linux icscf 2.6.27-11-generic #1 SMP Thu Jan 29 19:24:39 UTC 2009 i686 GNU/Linux

## **Client Terminal 2**

processor : 0  
vendor\_id : GenuineIntel  
cpu family : 6



model : 15  
model name : Intel(R) Pentium(R) Dual CPU E2160 @ 1.80GHz  
stepping : 13  
cpu MHz : 1203.000  
cache size : 1024 KB  
physical id : 0  
siblings : 1

MemTotal: 1018316 kB  
MemFree: 44608 kB  
Buffers: 121456 kB  
Cached: 458084 kB  
SwapCached: 2736 kB  
Active: 465040 kB  
Inactive: 418112 kB  
Active(anon): 166312 kB  
Inactive(anon): 196652 kB  
Active(file): 298728 kB

Distributor ID:Ubuntu  
Description: Ubuntu 9.04  
Release: 9.04  
Codename: jaunty

Linux ims-desktop 2.6.28-19-generic #65-Ubuntu SMP Thu Sep 16 14:14:28 UTC 2010  
i686 GNU/Linux

### **Client Terminal 3**

processor : 0  
vendor\_id : GenuineIntel  
cpu family : 15  
model : 1

model name : Intel(R) Celeron(R) CPU 1.70GHz  
stepping : 3  
cpu MHz : 1699.774  
cache size : 128 KB  
fdiv\_bug : no  
hlt\_bug : no

MemTotal: 507680 kB  
MemFree: 33644 kB  
Buffers: 75136 kB  
Cached: 202452 kB  
SwapCached: 23756 kB  
Active: 172840 kB  
Inactive: 228868 kB  
Active(anon): 54256 kB  
Inactive(anon): 127344 kB  
Active(file): 118584 kB

Distributor ID:Ubuntu

Description: Ubuntu 9.04  
Release: 9.04  
Codename: jaunty

Linux wimax2-desktop 2.6.28-19-generic #66-Ubuntu SMP Sat Oct 16 17:39:04 UTC 2010 i686  
GNU/Linux

#### **Client Terminal 4**

processor : 0  
vendor\_id : GenuineIntel  
cpu family : 6  
model : 23  
model name : Pentium(R) Dual-Core CPU E5300 @ 2.60GHz  
stepping : 10

cpu MHz : 1203.000  
cache size : 2048 KB  
physical id : 0  
siblings : 2

MemTotal: 2052412 kB  
MemFree: 552056 kB  
Buffers: 183280 kB  
Cached: 999436 kB  
SwapCached: 1072 kB  
Active: 982216 kB  
Inactive: 401168 kB  
Active(anon): 124852 kB  
Inactive(anon): 134864 kB  
Active(file): 857364 kB

Distributor ID:Ubuntu

Description: Ubuntu 9.04  
Release: 9.04  
Codename: jaunty

Linux imuser-desktop 2.6.28-19-generic #66-Ubuntu SMP Sat Oct 16 17:39:04 UTC 2010  
i686 GNU/Linux

### **Client Terminal 5**

Distributor ID:Ubuntu

Description: Ubuntu 9.04  
Release: 9.04  
Codename: jaunty

Linux liveuser-desktop 2.6.28-19-generic #66-Ubuntu SMP Mon Nov 1 10:30:05 UTC 2010  
i686 GNU/Linux

The information presented below was adapted from [77]:

|                     |   |
|---------------------|---|
| Processor / Speed:  | Intel® Centrino® Duo mobile processor technology, featuring: Intel® Core™2 Duo mobile processor T7300/T7500/T7700 (4 MB L2 cache, 2/2.2/2.4 GHz, 800 MHz FSB) |
| Core Logic Chipset: | Mobile Intel® GM965 Express   |
| RAM:                | Up to 2 GB of DDR2 533/667 MHz memory   |
| Video Subsystem:    | Mobile Intel® GM965 Express Chipset with integrated 3D graphics, featuring Intel® Graphic Media Accelerator (GMA) X3100                                       |
| Modem:              | 56K ITU V.92 PPT approved, Wake-on-Ring ready   |

# APPENDIX C

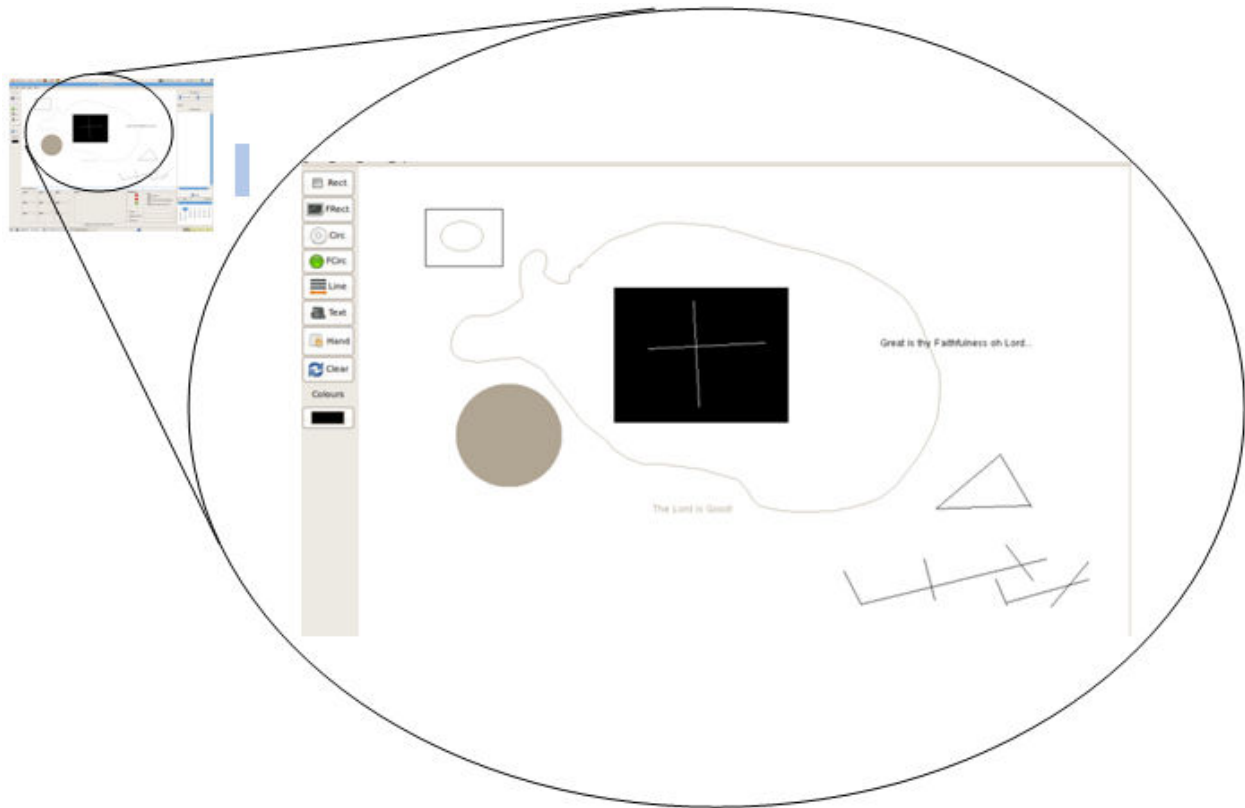
## TEST-BED SOFTWARE

This appendix details the implementation software used to ensure reproducibility of the results obtained and presented in this thesis.

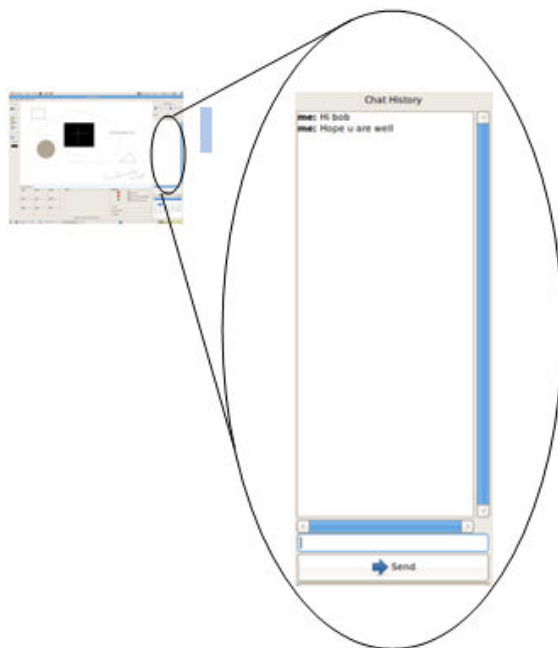
### **UCT IMS Client and Added Support Features of the Whiteboard Application**

The UCT IMS Client [73] was used as the access terminal to the virtual classroom application server. System requirements and installation instructions may be found at: <http://uctimsclient.berlios.de/>. The client was extended to support virtual classroom functionality. The source code can be found on the accompanying CD-ROM in Appendix D.

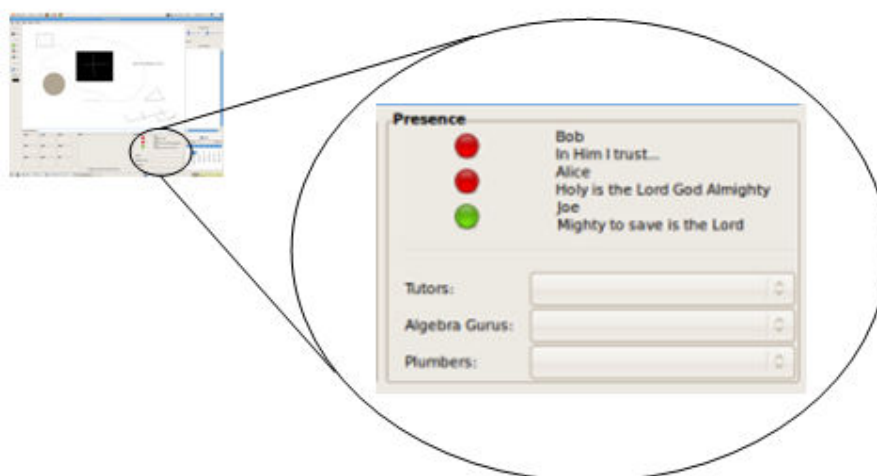
Below are images of the GUI of the UCT IMS Client Virtual Classroom application GUI developed during the course of this thesis.



**Figure C.0.1 The UCT-IMS Client Virtual Classroom whiteboard interface**



**Figure C.0.2 The UCT-IMS Client Virtual Classroom chat interface**



**Figure C.0.3 The UCT-IMS Client Virtual Classroom Presence and status interface**

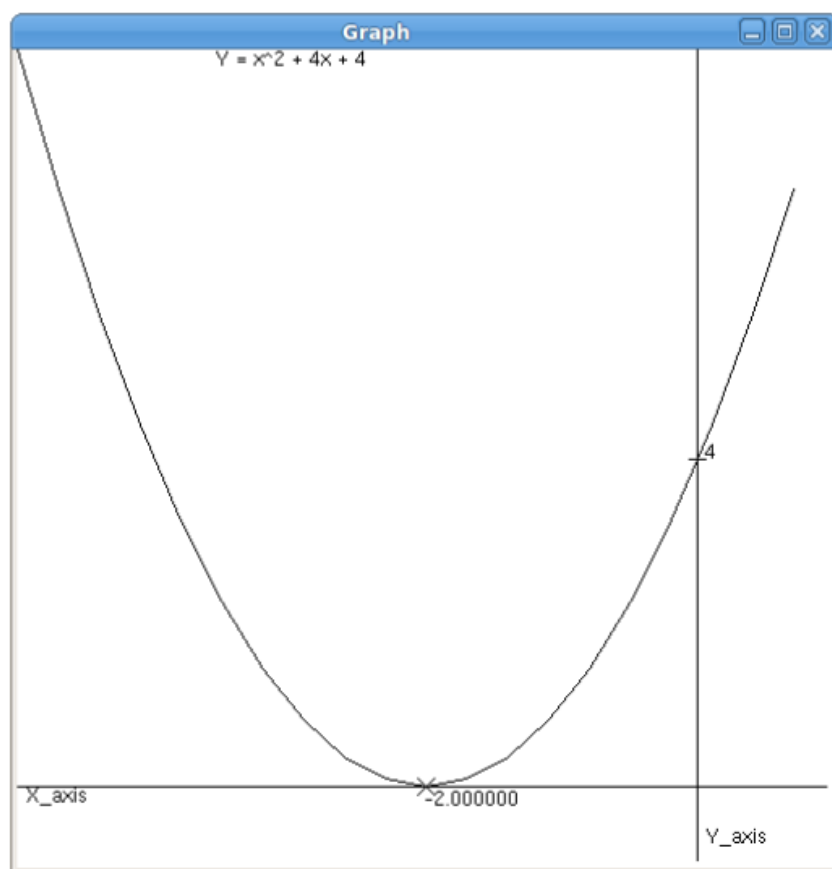
### **Mathematics Related Support Features**

Mathematics is considered to be one of the more demanding subjects. About 93% of first year university students in South Africa do not have sufficient mathematics knowledge to cope with first year university course materials [67]. Following the release of the New National Curriculum in 2008, mathematics or mathematics literacy became compulsory subjects for all students in South Africa [68]. This places a higher demand on the SADE to provide more mathematics teachers or train the current ones to handle the increased number of students taking the subject.

The benefits of e-learning can be further realized in such a context. Students can sit and watch a broadcast of topics and have online materials (podcasts, audio files, etc) available for download. Questions can be discussed amongst friends and only those that are not solved amongst friends will need to be brought to the teacher for a class discussion. This reduces the burden on the individual teacher making students, who are more knowledgeable about a certain subject, teachers in their own right. Since virtual classrooms are geographically independent, students from all over South Africa can assist students in different areas of the country using virtual classrooms.

The application is further equipped with tools that support the discussion of mathematics specific questions. These tools include plotting of quadratic equations complete with labelling of asymptotes and points of intersections. The user selects these tools from a drop

down menu on the menu panel of the application interface. The application requires the user to enter a quadratic equation of the form  $ax^2 + bx + c$ . Only the coefficients  $a$ ,  $b$  and  $c$  are required in the pop-up window presented to the user upon selecting the plotting tool. After the user enters these three values, the application solves the equation (calculates the  $x$  and  $y$  intercepts) and generates a series of points to be plotted on a graph that is displayed to the user when complete. The user has the option to label the plotted graph to differentiate it from other graphs that might be drawn during the session. The equation of the plotted graph is sent to members of the sessions. Each participating member re-drew the graph upon receiving the equation. Figure B.4 presents an example of a plot of a linear equation,  $y = x^2 + 4x + 4$ .



**Figure B.4: The plot graph interface**

### **Whiteboard Application Server**

The whiteboard application was used to provide the server functionalities of the virtual classroom application. The source code may be found on the accompanying CD-ROM in Appendix D.



**Fraunhofer Fokus open IMS Core [75]**

The Fraunhofer Fokus Open IMS Core was used to provide the IMS core elements. Details of the operation of the Open IMS Core, as well as download, installation and configuration instructions may be found at: <http://www.openimscore.org/>.

University of Cape Town

# APPENDIX D

## Virtual Classroom Session Demo

This section gives more details on how to setup a virtual classroom session.

The application requires the following open source software:

1. UCT IMS Client
2. Fokus open IMS Core
3. Whiteboard Application Server (WAS)

Once the above mentioned tools are installed, excluding the WAS which does not require installation, the following steps need to be followed. (Instructions on how to install the UCT IMS Client can be found at: <http://uctimscient.berlios.de/>. Instructions on how to install the open IMS core can be found at <http://www.openimscore.org/>)

1. Add the whiteboard server to the FoHSS and run it. Instructions on how to do this can be found at: <http://uctimscient.berlios.de/>.
2. Run the UCT IMS client, specifying the IP address of the P-CSCF.
3. Once registered with the IMS core, click the “E-learning” tab on the UCT IMS Client interface.
4. Virtual classroom session can be initiated by clicking the “Start session” button on the client interface. Once “Start Session” is clicked, the whiteboard GUI interface should pop up.
5. Run a second client and start another session (you may need to restart the first client – the whiteboard server currently does not initiate communication with clients, therefore the second client may be informed of the first but not vice versa)
6. Once the first client has been restarted, they can now engage in a virtual classroom session using Instant Messages only.
4. If you wish to include voice communication, initiate a voice call session using the UCT IMS Client GUI.

# APPENDIX E

## ACCOMPANYING CD-ROM

The CD-ROM included with this thesis contains the following files and information:

- Publications – Copies of paper which have been accepted to conferences, written or co-written by the author of this thesis, can be found in the directory labeled “Publications”
- Research Literature – Electronic versions of some of the research papers and other literature used in this research can be found in the directory labeled “Research Literature”
- Results – The results obtained during the performance test carried out for this thesis can be found in the directory labeled “Results”.
- Software – All the source code which was developed and modified for the purpose of the implementation of this project can be found in the directory labeled “Software”
- Thesis – An electronic copy of this thesis document can be found in the directory labeled “Thesis”

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